REPORT RESUMES

ED 013 983 24 AA 000 251

THE INTERFACE BETWEEN STUDENT AND SUBJECT MATTER.
BY- GLASER, ROBERT AND OTHERS
PITTSBURGH UNIV., PA., LEARNING RES. AND DEV. CTR.

PUB DATE 66
CONTRACT OEC-3-16-043
EDRS PRICE MF-$0.75 HC-$5.68 140P.

DESCRIPTORS- *INSTRUCTIONAL TECHNOLOGY, *PROGRAMED INSTRUCTION, *COMPUTER ASSISTED INSTRUCTION, *AUTOINSTRUCTIONAL AIDS, *TEACHING MACHINES, RESPONSE MODE

THE AUTHOR EXAMINES THE DISPLAY AND RESPONSE CHARACTERISTICS BY WHICH A STUDENT CAN INTERACT WITH A SUBJECT-MATTER DISCIPLINE. THIS DOCUMENT IS A REVISION OF A REPORT ISSUED UNDER THE SAME TITLE IN 1964 (ED 003 167). THE TERM "INTERFACE" IS USED TO REPRESENT THE DISPLAY MEDIA AND CONTROLS WITH WHICH THE STUDENT HAS DIRECT CONTACT. THE DISPLAY CONSISTS OF INFORMATION INPUTS TO HUMAN SENSORY CHANNELS. THE CONTROLS CONSIST OF TRANSDUCERS FOR CONVERTING HUMAN RESPONSES SO THEY CAN BE DETECTED. CHAPTER 1 INTRODUCES THE PROBLEM, ITS BACKGROUND, AND THE APPROACH TAKEN. CHAPTER II CONSIDERS HOW SUBJECT-MATTER PROPERTIES AND REQUIREMENTS FOR LEARNING CAN IMPOSE CONDITIONS UPON THE DESIGN OF AN INSTRUCTIONAL INTERFACE. CHAPTER III REVIEWS PHYSIOLOGICAL AND HUMAN FACTOR CONSIDERATIONS RELATED TO VISUAL AND AUDITORY INFORMATION CHANNELS AND RESPONSE OUTPUTS, BUT IS PRIMARILY CONCERNED WITH THE TECHNIQUES AVAILABLE FOR USING THESE HUMAN CAPABILITIES IN THE EDUCATIONAL ENVIRONMENT. PRESENTLY AVAILABLE DEVICES, TECHNICALLY FEASIBLE DEVICES, AND POTENTIALLY AVAILABLE DEVICES ARE CONSIDERED. CHAPTER IV PRESENTS (1) THE GOALS AND TASKS OF THE RESEARCH AND DEVELOPMENT NEEDED TO FOLLOW UP CONCEPTS DISCUSSED IN THE FIRST THREE CHAPTERS, (2) THE SPECIAL PROBLEMS THAT CAN BE INVESTIGATED, (3) THE TYPE OF INTERFACE EQUIPMENT INDICATED BY SUBJECT-MATTER CONSIDERATIONS AND INSTRUCTIONAL REQUIREMENTS, AND (4) OVERALL CONSIDERATIONS WITH RESPECT TO COMPUTER AND INSTRUCTIONAL PROGRAMING. (AL)

BR 5-0253
PA 24

UNIVERSITY OF PITTSBURGH - LEARNING R & D CENTER

TECHNICAL
REPORT 5

THE INTERFACE BETWEEN STUDENT AND SUBJECT MATTER

ROBERT GLASER, WILLIAM RAMAGE, AND JOSEPH LIPSON

AA000251

THE INTERFACE BETWEEN STUDENT AND SUBJECT MATTER

Robert Glaser
William W. Ramage
Joseph I. Lipson

Learning Research and Development Center

University of Pittsburgh

1964

Reedited, 1966

The research reported herein was performed pursuant to Contract OE-3-16-043 with the Office of Education, U. S. Department of Health, Education, and Welfare. Contractors undertaking such research under Government sponsorship are encouraged to express freely their professional judgment in the conduct of the research. Points of view or opinions stated do not, therefore, necessarily represent official Office of Education policy or position.

Table of Contents

CHAPTER I

INTERFACE CONCEPTS

PREFACE 3
INTRODUCTION 4
THE BACKGROUND OF THE PROBLEM 6
    Re-examination of the Technical and Theoretical Bases of Audiovisual Instructional Materials 6
    Programmed Instruction 7
    Subject-Matter Modernization and Reanalysis 7
    Computer-Assisted Instructional Systems 8
    Presentation Modality 8
    Man-Computer Communication 9
    Engineering Psychology 9
    Categories and Properties of Human Behavior 9
    Curiosity and Exploratory Behavior 11
APPROACH 12
    Assumptions and Limitations 15
REFERENCES 17

CHAPTER II

SUBJECT MATTER AND INSTRUCTIONAL FACTORS

PREFACE 23
SUBJECT-MATTER IMPLICATIONS FOR AN INTERFACE 24
    Mathematics 24
    Reading 28
    Science 36
    Summary of Subject-Matter Implications for an Interface 43

INTERFACE ASPECTS AND INSTRUCTIONAL REQUIREMENTS 46

Illustrative Instructional Procedures 46

Sample Lesson in Mathematics 51

Summary 55

POSSIBILITIES OF A GENERAL PURPOSE STUDENT-SUBJECT-MATTER INTERFACE 55

Basis for Estimating Subject-Matter Range of a General Purpose Interface 56

Hierarchy of Stimulus and Response Provisions 58

Response Elements for a General Purpose Interface 58

Limits of a General Purpose Instructional Environment 59

REFERENCES 61

CHAPTER III

INTERFACE EQUIPMENT CONSIDERATIONS

PREFACE 65

VISUAL COMMUNICATION 66

Coded Displays 69

Film Projection Devices 71

Cathode-Ray Tube Displays 75

Electroluminescent Displays 83

AUDITORY COMMUNICATION 89

General Considerations 90

Stereotyped Sound Displays 90

Generated Sound Displays 92

Comparison of Display Methods 98

Speech Recognition 99

RESPONSE DEVICES 101

General and Human Engineering Considerations 102

Experimental Devices 103

Device Application 110

REFERENCES 111

CHAPTER IV

RESEARCH AND DEVELOPMENT

PREFACE 115
PRINCIPAL TASKS 116
PROBLEMS OF INVESTIGATION 117
    Basic Instructional Problems 117
    Equipment Development Problems 123
SUPPORT TASKS 127
REFERENCES 131

APPENDIX

FORCE LESSON FOR SCIENCE INSTRUCTION 133
    Determination of Entering Behavior 136
    Generalization Display 136
    Gradual Progression 136
    Reinforcement 138
    Prompting 138
    Fading of Prompts 141

Chapter I

INTERFACE CONCEPTS

Preface

It is the purpose of this report to examine the dimensions along which subject matter can be presented to a learner and the dimensions along which he can respond to it and work with it in the course of learning. In engineering, the term "man-machine interface" is commonly used to describe the means by which a human comes into contact with a machine. In engineering psychology, much work has gone into the experimental analysis of the appropriate display and response characteristics by which a human can communicate with the machine and provide an optimal man-machine unit or system.

The concern of this report is similar to the extent that it examines the display and response characteristics by which a student can interact with a subject-matter discipline. Borrowing from engineering terminology it seems appropriate to say that this report is concerned with the student-subject-matter interface. Chapter I introduces the problem, its background, and the approach taken.

Introduction

When one thinks of the problem of presentation of subject matter to the learner, one thinks of the ubiquitous term "instructional media," which conveys the range of materials, such as books, tape recorders, and audiovisual aids, by which subject matter is displayed to the student. The primary contact of the student with his subject matter is through the printed page with supplementation by audiovisual aids and field and laboratory experiences. Despite all the service that printed materials and traditional aids have provided, it seems appropriate, in light of present engineering technology and behavioral science, to examine new possibilities for providing interaction between the student and his subject matter environment. It seems possible to present the learner with ways of seeing and manipulating his subject matter which extend and enrich his contact with it, and to form a learning environment in which subject matter dimensions are less drastically reduced than in a primarily paper and print learning environment.

In broad outline, a learning environment consists of the display of the subject matter to the student, controls or manipulanda (a pencil or a teaching machine) by which the student works with the subject matter, and some logic between the display and controls. The term interface, as used in this report, comprises the display media and controls with which the student is in direct contact. The display consists of information inputs to human sensory channels. The controls consist of transducers for converting human responses so they can be detected. If the objective of a teaching sequence is the manipulation of numerical or alphabetical symbols, the combinations of sense modalities which are required and the manner in which students should manipulate these stimuli in order to learn to generalize and apply their competence to a wide range of future instances must be considered. The manipulanda are related to the nature of the student response, the kind of manipulation required by subject-matter characteristics, the nature of the particular learning process, and the degree of subject-matter competence to be attained. For example, concepts of more or less, of speed and acceleration, of rate of change in functional relationships as related to the terms of an equation, and conceptual models in science may be taught best if the student can operate a display in which the results of manipulating a variable are shown or fed back in a dynamic fashion in terms of its influence on related variables or outcomes. This feedback requirement is an integral part of the display and response logic of an instructional interface. Feedback characteristics are dictated by the kind of logic (both subject-matter and teaching logic) that is established between student response to the display and a change in the display as a result of the response.

The responsive relationship between subject-matter display and manipulation of it by the learner is one of the essential aspects of the student-subject-matter interface. A student learns by manipulating the objects and concepts in his environment; the environment is responsive to his manipulation and in some way the student is informed of the results of his subject-matter operations. Subject-matter connections, subject-matter principles, and approaches to subject-matter problem solving are learned from manipulation of events, real or symbolic. It is a basic premise of this report that since the manipulation of subject-matter events is the primary means by which the student learns, the manipulation should take place on the basis of a wide range of display and response modes. These modes are dictated by subject-matter characteristics and requirements of the learning process and made possible by the application of modern engineering developments in display and response technology. Instructional environments, as a result, are less limited and less impoverished than is the case with much present instruction by the paper and pencil emphasis of most instructional materials.

The logic of the instructional environment is the relationship between display, response, and feedback display. This logic is a function of (1) the properties and structure of the subject matter, e.g., the consonant b has the sound /b/, 11 plus 1 are 12 in certain systems, or rate = distance/time, and (2) the teaching strategy and instructional requirements demanded by the kind of behavior being taught, e.g., the aptitudes and prior skills with which the student enters the instructional situation, the degree of accuracy or precision required before reinforcement occurs, or the kind of error-correcting prompts that are supplied. The logic is built into a workbook, into programmed instructional material, or into the computer logic of a computer-assisted instructional device. This report, as will be seen, assumes computer-based logic of some kind behind the display and response interface. However, the emphasis of the report is upon display, response, and feedback equipment and media and not upon computer operations. The present state of computer technology and of instructional practice indicates that computers can handle the problems posed to it by instructional requirements, and that the pressing need is for specification of the display and response requirements to be provided for the learner.

The Background of the Problem

The notions expressed above grow out of recent activity in education, psychology, and engineering. These converging lines of endeavor provide a rich background for this report.

Re-examination of the Technical and Theoretical Bases of Audiovisual Instructional Materials

In recent years, there has been much research and development activity on instructional media spearheaded by the Title VII NDEA program and the Department of Audiovisual Instruction of the National Education Association. The Technological Development Project, under the direction of James D. Finn, has produced a series of papers which review the history of educational technology (Anderson, 1961; Saettler, 1961), available teaching machine devices and programmed materials (Finn & Perrin, 1962), the use of audiovisual instrumentation (Finn, Perrin, & Campion, 1962), and design problems involved in development of instructional equipment (Leverenz & Townsley, 1962). In special supplements to the Audiovisual Communication Review, behavioral scientists have considered the implications of learning theory (Meierhenry, 1961) and of research in perception (Hochberg, 1962) for audiovisual utilization. In the latter volume Hochberg suggests the possibilities of dynamic, pictorial displays in education and their potential for the control of student attention. He points out the possibility of research in and development of visual displays which achieve control of visual attention in a way similar to the attention brought about by "good composition" of a picture. The scientific study of such aspects of display for educational purposes has had little history. Carpenter (1960) has discussed the necessity for exploratory research on the capabilities of new communication technology, such as television, for mediating educational experiences. These writers and others indicate an increasing concern of audiovisual specialists with defining more rigorously the principles underlying their work.

Programmed Instruction

Within the past ten years programmed instruction has focused the interest of scientists studying learning on the instructional process, and the instructional sequence has increasingly become a matter for experimental investigation. The concepts underlying programmed instruction have also forced the behavioral analysis of subject-matter knowledge and skill (Lumsdaine & Glaser, 1960; Filep, 1963; Glaser, 1964). The work to date has been restricted by the adoption of stereotyped presentation formats and the imposition of the paper and print media. Significant advances can be made by research and development carried out in instructional environments where display and response capabilities provide greater flexibility for adaptation to subject-matter properties and learning requirements (Moore, 1963; Skinner, 1961; see section on computers below).

Subject-Matter Modernization and Reanalysis

The activity of subject-matter scholars in analysis of their disciplines for teaching has been a welcomed trend in education. In science, mathematics, English, social studies, reading, and foreign language instruction, new displays and means of interacting with the subject matter, requiring simulation and manipulation of subject-matter situations, have been encouraged. Foreign language instruction was one of the earliest to adopt mechanized auditory presentation. Unfortunately, the method was adopted before it could be influenced by the concepts of programmed instruction.

Computer-Assisted Instructional Systems

The interest shown in computer-based instructional systems has led to some potentially fruitful developments (Coulson, 1962). While the emphasis in automated instruction has been on internal computer-based logic (Bitzer, Braunfeld, & Lichtenberger, 1962), examples are now available which show innovations in computer-controlled displays. Licklider (1962), for example, used oscilloscope displays to teach German and graphic representation of equations, and Uttal (1962) employed an electroluminescent character generator in teaching stenotype. The work of Licklider is a good illustration of the potential of new technological developments for an instructional interface. In a computer-assisted arrangement, the student worked with an oscilloscope display unit and a typewriter response unit. As a means of developing an understanding of the relations between symbolic and graphical representation of mathematical functions, the student typed coefficients of an equation on the typewriter, and the oscilloscope screen displayed the corresponding curve. The arrangement permitted the student to use the automated context for exploration of the concepts he was learning. (Such a setup also suggests the development of a simple computer language by which a teacher might design teaching sequences in an automated classroom.)

Presentation Modality

Chapman and Carpenter (1962) indicate that the major research issue in the automation of instruction is the problem of presentation modality. They ask for research on the appropriateness of modality of presentation for different concepts; in other words, are certain concepts better learned visually, auditorily, or by combinations of modalities? Teager (1962) indicates the importance of the development of graphic input and output facilities in automated instructional systems that can remove the student from the restrictions of keyboards, limited sets of characters and one-dimensional inputs. He points out that in the use of modern technology and computer-assisted instruction, major innovations are required in the form of input and output consoles. "To make it effective and efficient, much thought must be given to psychological, mechanical, and programming considerations.

Slavish adoption of standards that were developed for essentially different usages will only delay the day of more fruitful human-machine cooperation" (p. 280).

Man-Computer Communication

Related to the above has been the work by mathematicians, computer technologists, and engineers on control and display consoles for interaction with high-speed computer systems. Experimental consoles have been constructed for mathematical analysis, engineering drawing and testing, and linguistic analysis (Licklider & Clark, 1962; Stotz, 1963; Sutherland, 1963). These developments, which will be discussed in more detail, provide the physical equipment capability by which subject matter can be displayed to and manipulated by the student.

Engineering Psychology

Work in the field of engineering psychology and human engineering has been referred to above. However, the major significance of this area for a student-subject-matter interface is that knowledge has been codified with respect to the optimal conditions and limits for the interaction of humans and machines, for the presentation of information in various sensory modalities, and for the design of response mechanism (Morgan, Cook, Chapanis, & Lund, 1963).

Categories and Properties of Human Behavior

Increasingly, psychologists have begun to analyze the behavioral properties of human performance. In the past more emphasis was devoted to learning phenomena and individual difference effects. However, as psychologists turned their attention to training and education (Glaser, 1964), they were faced with the necessity for behaviorally analyzing the tasks on which they were working; this is a necessity in dealing with real-life tasks and real subject matter. In contrast, in the psychological laboratory, an investigator decides upon and constructs or preselects an experimental task which has stimulus and response characteristics pertinent to his problem. More and more experiences are indicating the importance of research which considers instructional variables in terms of the characteristics of the properties of the tasks to be learned. Along these lines Bruner (1960) has emphasized the structure of subject matter. Gagné (1965) has related the characteristics of a variety of learning tasks (response differentiation, association, multiple discrimination, behavior chains, class concepts, principles, and strategies) to the description of educational objectives and the kind of learning conditions required for different objectives. Skinner (1957) has consistently attempted to consider the properties of behavior in conjunction with this experimental analysis. Lane (1965) in language learning and Mechner (1965) in science instruction carry forward Skinner's emphasis on the analysis of behavior. Carroll (1964) identifies the stimulus-response classes that require specification in reading instruction. Melton (1964) has edited a book on the categories of human learning to explore the utility of past and possible future categories for the scientific analysis and technology of human learning. Fleishman (1962) suggests further that task properties change as learning progresses and that students may call upon different combinations of abilities at different stages of learning.

The significance of these studies is that learning technology and instruction must consider the stimulus (display) and response characteristics of the learning task and relate these stimulus and response properties to the effective conditions for learning. The increased specificity of the different categories of human learning should suggest a wide range of stimulus and response requirements. Research and development along these lines leading to effective instructional conditions will require an increased range of display and response mechanisms which can permit the freer use of variations in stimuli, responses, and modalities as dictated by learning categories, different learning stages, and individual differences in aptitude and background.

Curiosity and Exploratory Behavior*

Within the past decade, an increasing amount of research effort has been directed to the study of behavior generally labeled as curiosity and exploration (Fowler, 1965; Berlyne, 1960). Prior to 1950, research on curiosity and exploratory behavior was all but absent except for a few isolated instances. In infrahuman studies, research has been aimed at the discovery and identification of variables which serve to elicit and maintain behavior of this kind in the absence of conventional motives such as hunger or thirst or other conditions of deprivation. The specific responses which were observed were such behaviors as orienting, approaching, investigating, manipulating, etc. The significant variables influencing such exploratory responses have been characterized as stimulus objects or patterns that are novel, unfamiliar, complex, surprising, incongruous, asymetrical, etc. All these aspects can be generally described as change in the stimulus complex displayed to the individual. Research has indicated that the strength of exploratory behavior that is elicited is positively related, within limits, to the degree of change in the stimulus situation provided by the novel, unfamiliar, or incongruous stimulus situations introduced into the environment. Too great or too abrupt a change, however, is disrupting and may preclude exploration. In complex situations an individual's encounters change by way of his interaction with or manipulation of the elements of the stimulus pattern. Such interaction provides the stimulus change which can elicit curiosity and exploratory behavior.

Investigations have also demonstrated that behaviors are learned that lead to a change in the stimulus display. Thus, in addition to stimulus change eliciting exploratory behavior, experiments (primarily with animals) show that organisms will respond in order to secure novel, unfamiliar stimuli--in general, stimulus change. Such findings have been obtained for a variety of response modes, e.g., auditory, visual, and proprioceptive. The stimulus change, not only the initiating stimulus, can occur in a variety of modes. For example, exploratory manipulative responses may be learned on the basis of the changes in proprioceptive stimulation which accompany them (Harlow, 1953). In general these findings demonstrate that stimulus change or sensory variation may be employed to selectively reinforce, and thereby strengthen and maintain, behaviors which result in stimulus change, and that this change or variation in the stimulus situation will serve concomitantly to elicit exploratory behavior. Stimulus change as a reinforces appears to be quite similar in its operation to other kinds of reinforcing stimuli, and the phenomena of acquisition and extinction, the effect of magnitude of reinforcement, delay of reinforcement, and schedule of reinforcement influence exploratory and curiosity behavior as they do other learned behavior.

---

*We are indebted in this section to a working paper prepared for this project by Professor Harry Fowler of the University of Pittsburgh.

With respect to the student-subject matter interface, this work suggests that a student's curiosity and explanations may be both elicited and selectively maintained in an instructional (learning) environment which provides for variation and change in both the stimulus characteristics of subject materials confronting the student and also the responses required of him by these materials. Development of an appropriate interface which could provide a relatively continuing, manipulative interaction between the student and subject-matter stimuli would permit a continous flow of variation in both student stimulation and response requirements. An instructional sequence could be programmed so that a pattern of change is provided in stimulus and display characteristics. In addition, the reinforcing effects of stimulus change could be used to reinforce desirable subject-matter competencies. Along these lines, research and development with a range of display and response capabilities, can investigate the effects of curiosity and exploratory behavior as they relate to student learning.

Approach

The approach to an examination of innovations in the student's learning environment which is taken in this report postulates that the student-subject matter interface is a function of primarily two aspects:

(a) The stimulus and response properties of the subject matter. For example, learning to read aloud demands a printed, verbal stimulus situation, a vocal response, and some means of detecting the accuracy of this spoken response; learning to listen demands an auditory stimulus and listening response which is measured in some way by determining the results of having listened, such as carrying out spoken directions or summarizing the meaning of spoken communication; and learning to carry out the computational operations of multiplication demands presentation of a written or printed set of numbers and a written response, or, at a later state, a keyboard response on a calculator. (b) The learning requirements of the kind of behavior being taught. For example, in learning precise accents in a language laboratory, some procedure is required for detecting and evaluating the correctness of pronunciation so that the student is given informational and reinforcing feedback in order to facilitate his increasing accuracy; the teaching of language pronunciation further may require the continuous adjustment of what is accepted as a correct response as learning proceeds. Many ways of pronouncing a French _r_ may be acceptable for a beginning student while fewer ways are acceptable for the more advanced students. In teaching handwriting, it is often necessary to provide the student with guide lines and lines to trace which are gradually removed as skill increases. Furthermore, the terminal educational objectives of a lesson influence the way in which subject matter is presented. If the objectives require that a certain body of knowledge be memorized, that subject matter may be presented and learned in one fashion; however, if the objectives require that the student learn to solve problems in his subject matter or deduce its further implications, the material will be presented in a different way. Both of these aspects, the properties of the subject matter and the manipulations of the subject matter required for learning, dictate the environment presented to the student for effective learning.

In order to discover these properties and requirements, what is necessary is the application of techniques for analyzing subject-matter properties and for analyzing the differentiating characteristics of kinds of behaviors to be learned. The procedures for carrying out these kinds of analyses are at the present time far from well worked out and available for unambiguous use (Bloom, 1954; Gagné, 1965; Melton, 1964; Stolurow, 1964).

The design of innovations in an instructional interface, while dictated by the above considerations, is limited by the state of engineering technology with respect to techniques for displaying information and for detecting human responses. For example, in the present state of equipment development, it may be feasible to display alpha-numerical characters on a television tube; the student can change the nature of this display by selecting keys on a typewriter. It may be less feasible to have the student change the display by having his spoken response detected by voice recognition equipment. A further possible delimitation is the capability of a computer-like device to provide the necessary logic that mediates between display and response, so that a certain kind of response results in the presentation of a certain kind of display.

Several aspects, then, influence the development of student-subject-matter interfaces: subject-matter properties and learning characteristics, equipment capability, and mediating logic devices. These latter devices essentially are computers. The emphasis of this report is on the properties of the interface with which the student interacts with the subject matters. Implicit in this emphasis is the belief that there has been much less development with respect to subject-matter display and response interfaces than there has been for computers. It is further assumed that the demands placed upon a computer by real-time use in an instructional situation are probably within computer capabilities. What is required are ways for the student to communicate with the computer. Not to be minimized in this context, however, is the significant amount of supplementary computer programming, frequently called software, required in programming a computer for instructional purposes. Computer capabilities also provide the means whereby a computer-based instructional interface can be used for practical teaching purposes and significantly, can also be used for the detection, monitoring, and collection of measures of student learning in order to study important variables of human learning and the instructional process.

With the emphases just described in mind, this report approaches the task of examining innovations in the student-subject-matter interface in the following way: First, materials in several subject matters are examined and analyzed with respect to stimulus and response properties and learning characteristics. Second, a survey is made, on the basis of available literature and field trips, of engineering equipment developments for information display and response detection. Third, the subject-matter and equipment analyses are considered together in the development of suggestions for an interface research and development program and for the kinds of problems that must be explored to answer questions about the learning and instructional process and engineering questions for interface design.

Assumptions and Limitations

Certain assumptions which limit the scope of this report should be stated explicitly. The problem of primary concern is the interface and its use for subject-matter stimulus display, subject-matter manipulation, reordering, rearraning, etc., and response reception and feedback. Essentially this involves the way and the instrumentation by which the student communicates with the logic of the lesson plan. It is assumed that computer capability to handle this logic is adequate and available. Computer software aspects involved in programming the computer are not examined in detail, but are mentioned briefly in Chapter 4 since they will be a significant aspect to be studied and implemented, e.g., programming procedures, appropriate languages and associated compilers for instructional programming in various subject matters. Also not highlighted in this report are the problems associated with programming (in the sense of programmed instruction) of instructional sequences and providing appropriate conditions for learning. The instructional lessons which must be prepared for study will need to consider this aspect in relation to the interface capabilities.

Interface requirements in this report are oriented toward children in the elementary school grades or younger, essentially from nursery school through the sixth grade. Whether this emphasis is best as a starting point for considering automated learning environments in education is a matter of opinion. The following, however, do seem to be points in favor of an examination of the problem for young children: (a) Some work is already going on in man (adult)-computer interaction, but work which considers the elementary grades may provide easier material with which to work out initial problems (although when one analyzes the complexity of multiplication and division in relation to the capabilities of a child, the point is debatable). (b) It is being increasingly recognized that the potential of young children can be encouraged with devices (like creative toys) which are designed for their level of motor development. (c) Application of knowledge from the science of learning to new instructional media might be more feasible at stages of early learning in comparison to more complex adult learning. (d) Learning in nursery school and kindergarten which is not involved with learning particular subject-matter skills, like reading and arithmetic, but more related to general habits of thinking, imagination, and creativity, may be enhanced by the use of new media.

Despite this last statement concerning the learning of very young children, the orientation of this report is toward the teaching of subject matters, such as topics in science, reading, writing, and arithmetic. There has been too much of a tendency for educators and psychologists to concern themselves with teaching for the more abstract and "higher things" in education, like problem solving, creativity, and intuition. The interest in such abstractions has often led to the neglect of knowledge fundamentals upon which these higher order behaviors can be imposed. It is an assumption of this report that an expanded learning environment can more adequately investigate how attitudes of resourcefulness, concentration, interest in the subject-matter content can be provided in the course of school instruction.

References

Anderson, C. *History of instructional technology, I: Technology in American education, 1650-1900*. Los Angeles: Technological Development Project, 1961.

Berlyne, D. E. *Conflict, arousal, and curiosity*. New York: McGraw-Hill, 1960.

Bitzer, D. L., Braunfeld, P. G., & Lichtenberger, W. W. Plato II: A multiple-student, computer-controlled, automatic teaching device. In J. E. Coulson (Ed.), *Programmed learning and computer-based instruction*. New York: Wiley, 1962. Pp. 205-216.

Bloom, B. S. (Ed.) *Taxonomy of educational objectives*. New York: Longmans, Green, 1954.

Bruner, J. S. *The process of education*. Cambridge: Harvard University Press, 1960.

Carpenter, C. R. Approaches to promising areas of research in the field of instructional television. In *New teaching aids for the American classroom*. Stanford: Institute for Communication Research, 1960. Pp. 73-94.

Carroll, J. B. The analysis of reading instruction: Prospectives from psychology and linguistics. In E. R. Hilgard (Ed.), *Sixty-third yearbook of the National Society for the Study of Education, Part I: Theories of learning and instruction*. Chicago: University of Chicago Press, 1964. Pp. 336-353.

Chapman, R. L., & Carpenter, Janeth T. Computer techniques in instruction. In J. E. Coulson (Ed.), *Programmed learning and computer-based instruction*. New York: Wiley, 1962. Pp. 240-253.

Coulson, J. E. (Ed.) *Programmed learning and computer-based instruction*. New York: Wiley, 1962.

Filep, R. T. (Ed.) *Prospectives in programming*. New York: Macmillan, 1963.

Finn, J. D., & Perrin, D. G. *Teaching machines and programmed learning, 1962: A survey of the industry*. Los Angeles: Technological Development Project, 1962.

Fleishman, E. A. The description and prediction of perceptual-motor skill learning. In R. Glaser (Ed.), *Training research and education*. Pittsburgh: University of Pittsburgh Press, 1962.

Fowler, H. *Curiosity and exploratory behavior*. New York: Macmillan, 1965.

Gagne, R. M. The analysis of instructional objectives for the design of instruction. In R. Glaser (Ed.), *Teaching machines and programed learning, II: Data and directions*. Washington, D. C.: Nat'l Educ. Assn., 1965. Pp. 21-65.

Glaser, R. Implications of training research for education. In E. R. Hilgard (Ed.), *Sixty-third yearbook of the National Society for the Study of Education, Part I: Theories of learning and instruction*. Chicago: University of Chicago Press, 1964. Pp. 153-181.

Glaser, R. (Ed.) *Teaching machines and programed learning, II: Data and directions*. Washington, D. C.: Natl. Educ. Assn., 1965.

Harlow, H. F. Motivation as a factor in the acquisition of new responses. In *Current Theory and Research in Motivation: A symposium*. Lincoln, Nebraska: University of Nebraska Press, 1953. Pp. 24-49.

Hochberg, J. The psychophysics of pictorial perception. *Audiovisual communication Rev.*, 1962, *10* (5), 22-54.

Lane, H. F. Programmed learning of a second language. In R. Glaser (Ed.), *Teaching machines and programed learning, II: Data and directions.* Washington, D. C.: Natl. Educ. Assn., 1965

Leverenz, H. W., & Townsley, M. G. *The design of instructional equipment: Two views.* Los Angeles: Technological Development Project, 1962.

Licklider, J. C. R., & Clark, W. On-line man-computer communication. *Proceedings of the Spring Joint Computer Conference*. San Francisco, California, 1962, Vol. 21.

Lumsdaine, A. A., & Glaser, R. (Eds.) *Teaching machines and programmed learning: A source book*. Washington, D. C.: Natl. Educ. Assn., 1960.

Mechner, F. Science education and behavioral technology. In R. Glaser (Ed.), *Teaching machines and programed learning, II: Data and directions.* Washington, D. C.: Natl. Educ. Assn., 1965. Pp. 441-507.

Meierhenry, W. C. (Ed.) Learning theory and A. V. utilization. *Audiovisual communication Rev.*, 1961, *9* (5).

Melton, A. W. (Ed.) *Categories of human learning*. New York: Academic Press, 1964.

Moore, O. K. *Autotelic responsive environments and exceptional children.* Hamden, Conn.: Responsive Environments Foundation, Inc., 1963.

Morgan, C. T., Cook, J. S., Chapanis, A., & Lund, M. W. Human engineering guide to equipment design. New York: McGraw-Hill, 1963.

Saettler, L. P. History of instructional technology, II: The technical development of the new media. Los Angeles: Technological Development Project, 1961.

Skinner, B. F. Verbal behavior. New York: Appleton-Century-Crofts, 1957.

Skinner, B. F. Teaching machines. Scientific American, 1961, 205 (5), 90-102.

Stolurow, L. M. A taxonomy of learning task characteristics. Wright-Patterson AFB, Ohio: Behavioral Sciences Laboratory, 1964.

Stotz, R. Man-machine console facilities for computer-aided design. Proceedings of the Spring Joint Computer Conference. Detroit, Michigan, 1963.

Sutherland, I. E. Sketchpad, a man-machine communication system. Proceedings of the Spring Joint Computer Conference. Detroit, Michigan, 1963.

Teager, H. M. Systems considerations in real-time computer usage. In J. E. Coulson (Ed.), Programmed learning and computer-based instruction. New York: Wiley, 1962. Pp. 273-280.

Uttal, W. R. On conversational interaction. In J. E. Coulson (Ed.), Programmed learning and computer-based instruction. New York: Wiley, 1962. Pp. 171-190.

Chapter II

SUBJECT MATTER AND INSTRUCTIONAL MATTER

Preface

The general problem to be considered in this chapter is how subject-matter properties and requirements for learning can impose conditions upon the design of an instructional interface. To this end, Chapter II attempts to do the following: (a) analyze the stimulus and response requirements of arithmetic concepts and computations, elementary lessons in reading, and elementary science; (b) examine some instructional procedures to see how their requirements might be implemented in an environment which would provide a wide range of stimuli and manipulative responses; (c) provide an example of a specific learning sequence in which the designers would not be limited by conventional instructional media; (d) discuss the possibilities of a general purpose interface which could meet the stimulus and response requirements of the first two parts of this chapter. The consideration of subject-matter stimulus and response requirements, procedures for effective learning, and technological feasibility should provide basic information for the design of instructional tools which can help educators cope with the severe educational problems of our day.

Subject-Matter Implications for an Interface

The illustrative subjects to be considered are mathematics, reading, and science, all at the elementary school level. The question to be answered is how do these subject areas impose conditions upon the design of an automated interface. Examples will be presented to add clarity to the arguments. These examples are not intended to be most representative or most important in the subject areas from which they were drawn. Outlines of student skills in the areas of mathematics, reading, and science will be presented. After each subject area is discussed, a summary of the stimulus and response requirements for that area will be presented. A final summary covering the subject matter implications will also be made.

Mathematics

Mathematics in the primary grades involves the following subject-matter behaviors: (a) making the correspondence between sets of objects and a numerical representation (usually an oral representation at first); (b) discrimination of numeral shapes; (c) performing arithmetic operations as defined by the number systems; (d) recognizing patterns in the operations which can be performed with numbers and objects; (e) discriminating spatial properties, and (f) relating numbers to the properties of space. In addition to the above classes of learning activity, the student must acquire the computational skills relevant to these concepts. This above list of subject-matter objectives was compiled after surveying eight courses in elementary mathematics which are currently used in the United States.

Interface Requirements

Each of the subject-matter categories will be considered below in terms of the interface requirements for stimulus presentation and student response.

1. Making the correspondence between sets of objects and a numerical representation. For the early stages of education in developing the relationship between sets of objects and number representations, the instructional environment usually presents arrays of objects such as round discs, sticks, or toy animals. The student then matches the numerals with the proper set of objects by various response modes, e.g., by writing a numeral, selecting from alternative numerals in response to directions which essentially ask, "Which group has three dogs?" "How many things are in front of you on the table?" For very young children who have not yet learned to write the numerals or even to discriminate them in a visual display, an oral detection capability would be a requirement for the interface.

2. Discriminating numeral shapes. In order to teach the numerals which correspond to the number property of sets of objects, the interface must have a visual display mode. When the student has mastered the ability to relate arrays of three-dimensional objects to a number, the three-dimensional object presentation can be succeeded by a two-dimensional visual presentation of arrays of dots, squares, pictures of animals, lines, etc. The student response can now take place on a two-dimensional surface like a keyboard console. For example, the early lesson in the correspondence between a numeral and the number of objects it represents might involve a display of objects and a keyboard with the numerals on it. A sequence of object-numeral displays can be presented to the student with display and response variations designed to facilitate such learning effects as discrimination between set numerosity or generalization to sets of objects of different kinds having the same numerosity. Displays can be chosen which are reinforcing on the basis of the student's preference for certain pictured objects. The subject matter of mathematics determines that certain stimuli must be presented in the form of numerals and sets of objects; the manner of presentation is determined by the conditions for effective human learning.

3. Performing arithmetic operations. Once the correspondence between numbers and numerals is mastered by the student, little new interface capability is required for the lessons which develop the relationship

between numbers. For example, to teach the fact that 3 x 4 = 4 x 3 = 12, the same visual display of objects, pictures of objects and numerals may be used as for teaching the correspondence between numbers and numerals. The visual display of a number line, the animation of lessons, the possible use of color and other attention-maintaining features are more related to the problem of efficient teaching than to the subject-matter requirements.

4. Recognizing patterns in the operations that can be performed with numbers and objects. Wirtz, Botel, and Sawyer (1962) have emphasized that an important area of learning in mathematics is the search for pattern in numerical and spatial relationships and that elementary students should engage in the search for pattern in graded sequences of activity. Through this search for pattern, students can be led to considerations of operations involved in addition, subtraction, multiplication, division and various combinations of these operations. In addition, the student can be led to generate his own more sophisticated relationships which may prepare him for more advanced lessons. The generation of various patterns is a new requirement for the interface in arithmetic lessons. For example, the typical activity in the Math Workshop (Wirtz et al., 1962) is "What's My Rule." A series of numbers may be presented as follows:

"If you say	3	7	1	4	9	2	17	8	5	10
I answer	8	20	2	11	26	5	50	?	?	?"

The student is asked, "Find the rule and finish the answer line." The rule in the above case is multiply by 3 and subtract 1. A student may be able to finish the line without the verbal expression for the rule and thus be led to the formal arithmetic operation in terms of a familiar problem which he has solved. To complete the exercise above, the student need only put 23, 14 and 29 beneath 8, 5, and 10, respectively. Other exercises may involve the use of number lines and various two-dimensional number arrays. In some cases, the patterns may involve geometrical shapes and need not have numbers at all. By a graded sequence of pattern difficulty, young children can become quite sophisticated in their ability to continue the patterns without the verbal skill required to describe them. In order to accomplish this, the interface should have a visual presentation capability and a response mode which allows the student to select elements which continue the pattern. Prompting displays might be desired to provide search cues to elicit appropriate responses.

5. Discriminating spatial properties and relating properties of number to properties of space. The properties of space and the relation between numbers and the properties of space takes the student into the areas of geometry and functional relationships. The student learns to recognize a sphere, a cylinder, a square, and other geometric figures. At some point, he is taught to describe these figures, surfaces, and volumes in the precise language of numbers. For example, the student is able to identify a square, construct a square with straightedge and compass (Hawley & Suppes, 1960), and eventually define a square in terms of the numerical properties of its lines and angles.

In order to enable the student to deal with the properties of space, the following requirements for an interface are suggested: (a) The interface should develop the ability of the student to respond to three-dimensional problems. For example, the student may be shown a sphere and asked, "This object is a ____________________?" The student would be expected to respond with the word sphere. (b) The interface should develop the ability of the student to abstract the properties of three-dimensional figures when presented with a two-dimensional stimulus. For example, a screen or book may show a sphere in color and in perspective. In front of the student are several three-dimensional shapes. The student is asked, "Which of the objects in front of you is the same as (represented by) the picture on the screen?" (c) The interface should develop the ability of the student to use two-dimensional representations to visualize the properties of three-dimensional objects. For example, when shown a drawing of a three-dimensional object he has not before seen, the student should be able to construct a model of the three-dimensional object. (d) The interface should develop the ability of the student to use the two-dimensional representation to develop the point by point properties of space. This behavior covers the formal instruction in such topics as the calculation of surface areas, volumes, slopes, and centers of mass, by direct calculation or measurement on models. While seemingly beyond the elementary level, many aspects of these problems can be taught to young students through the use of manipulable models and representations.

Summary of Stimulus and Response Requirements. In order to meet the above subject-matter requirements, a summary list of interface provisions would include:

1. The means for presenting numerals, symbols and drawings.
2. The means for presenting and detecting numbers of objects.
3. The means for detecting which one of a group of objects is placed on a surface.
4. The means for presenting problems which require sequential operations and determining the sequential response of the student.
5. The means for detecting constructed responses such as the construction of a square with a ruler and compass, and the capability for guiding constructed responses involving lines.
6. Provision for presenting auditory as well as visual stimuli (e.g., for instructing very young students) and the detection of oral responses.

Reading

The reading program discussed here envisions bringing the student to the level of reading ability where he should be able to read aloud most of the words in the daily newspaper (not counting proper names) by phoneticizing unfamiliar words. Of course, ability in texting does not indicate mastery of the meaning of the word or the ability to use the word freely in constructed responses. The mastery of word meaning and word usage is another part of the language arts.

Sequence of Skills in Reading Instruction. In learning to read, the student must acquire the ability to discriminate between the letters of the alphabet, and he must be able to generalize to the many ways in which letters are formed. In the usual reading course the student must be able to respond with the appropriate sounds or various letter combinations, both regular and irregular. In devising a course of instruction, there are three major areas which must be considered. These are: (a) the entering behavior of the student with special attention to his vocabulary, psycho-motor skill, and ability to follow verbal instructions; (b) the linguistic structure of the language; and (c) the psychological conditions for acquiring and maintaining the needed responses.

While any instructional program must deal with such considerations as these, in reading they assume greater significance because of the background of investigation into each of the three areas and because of the lack of any convergence of opinion regarding the results and implications of these investigations. The situation is interpreted by Carroll (1964) in the light of work in programmed instruction:

> Some studies of programmed instruction suggest that different orders of presentation have alarmingly small effects. Thus, of what help is it to 'program' the order of presentation of the various components of reading behavior? Why not simply present a variety of words and their pronunciations and allow the child to infer, for that matter? Essentially, of course, that is what is done in some kinds of contemporary reading instruction; but, in an effort to remedy the presumed inefficiency and failures of such a system, there are other systems which lay great stress on the programming of letter recognition and the development of grapheme-phoneme correspondences. At the present time, there is no adequate theoretical or empirical basis for deciding among these or other systems....
>
> For example, research in the field of reading does not enable us to say with certainty in what order the various processes in word recognition are best learned. To what extent is grapheme recognition prerequisite to the recognition of the whole pattern of a word? To what extent is it feasible to teach grapheme-phoneme response habits in the earliest phases of word-recognition practice?

> If this is feasible, should early teaching of grapheme-phoneme correspondences be based only on a selection of highly regular correspondences, or should the child be presented with a certain degree of irregularity and variety in order to condition him to the full range of irregularity of English orthography? These and many other questions arise from the kind of psychological and linguistic analysis of the task of reading.... (Pp. 350-351).

Grapheme-phoneme correspondences can be taught to very young children with presumably limited vocabularies as in O. K. Moore's typewriter program. Other programs (Buchanan, 1963) clearly state that the program is designed for a child who can speak fluently and has a vocabulary larger than he is likely to encounter in reading instruction. Much of the confusion in competing methods of reading instruction seems to result from a lack of consideration of the entering behavior which each program assumes, often without explicit definition.

At any rate, Carroll's comment on the strategy of reading instruction will lay the basis for the approach taken here.

> Generally, we believe that teaching becomes a relatively straight-forward and simple operation, once an adequate analysis of the behavior to be taught has been made and a program of instruction has been planned which features each separate item to be learned in its proper order and in its proper behavioral setting. A direct rather than an indirect approach is to be taken. For example, a proper strategy for increasing vocabulary is to determine students' vocabulary needs by appropriate diagnostic testing, then proceed to teach the items identified, one by one, at some appropriate rate of introduction (p. 352).

Viewed in this light, an order of presentation of items which is developed in terms of the student's entering behavior is important to the design of instructional sequences. A linguistically based sequence, while not necessarily the only desirable sequence, has the important advantage of setting forth the items of instruction according to a scheme of analysis which assures coverage of all the important aspects of language instruction and which can easily be integrated with a specification of entering behavior and be programmed according to a psychological analysis of the responses to be learned. For example, linguistically designed programs may indicate that words involving the short _a_ sound, /ae/ as in _apple_, should be introduced first (Buchanan, 1963). Carroll informs us that "There is evidence ... that the teaching of the mechanics of speech reconstruction ... is best done with materials which are maximally meaningful to the learner, e.g., words that are labels of things of interest to the learner or very simple sentences that convey an interesting or useful message" (p. 338). The combination of these two precepts results in the use of _am_, _an_, _ant_, _man_, _mat_, _tan_, _pan_, _fat_, and _fan_ in the first unit of instruction of Buchanan's _Programmed Reading_.

The following instructional sequence which is due to Fries and reported by Markman (1963) shows the orderly coverage of the subject matter which is possible in a program designed from linguistic considerations:

1. Student learns that symbols represent sounds.
2. Student learns upper-case letters of alphabet in sequential order: stroke letters, circle letters, and combinations of stroke and circle. Student then learns corresponding lower-case letters.
3. Student learns left to right movement of writing.
4. Student learns simple words for instant recognition. These conform to the pattern _bad_, _bat_, _bud_, _bet_, _bit_, _man_, _mat_, _tan_, _pan_, _pie_, _am_, _an_, _fat_, _fan_, etc.
5. Student learns words introduced in the following order:
    a. simple regular spellings (hat, hit)
    b. simple regular-irregular spellings (cup, son)
    c. simple irregular (who, me)
    d. compound regular (ship, with)
    e. compound regular-irregular (muff, dream)
    f. compound irregular (busy, mother)

6. Student learns to read sentence patterns as soon as possible.

7. Student has opportunity to use most interesting words as soon as possible (nose cone, re-entry). (Pp. 73-77)

Buchanan Programmed Reading. Generally, the Fries' requirements are met in Programmed Reading by Cynthia Buchanan, for the Sullivan Associates. The basic technique is that of stimulus generalization which is defined as written symbols used in one-to-one correspondence with their sound values so that the student can generalize within the system he has learned. In addition, a small array of sight words (words which do not conform to the sound which the student has been taught to match with a letter) is used to generate more natural sentences. The stimuli chosen result from an attempt to enter into the world of the beginning reader. This beginning reader is one who is a fluent speaker whose vocabulary exceeds that of any first course in reading. In contrast to Fries approach, this program makes extensive use of pictures as prompts in discrimination training and as a motivational factor.

The program is divided into a prereading, primary and second series. In the prereading program the student learns: (a) to discriminate and print letters of the alphabet; (b) to associate phonetic values for eight of the letters; and to read a limited vocabulary based on these letters, e.g., ant, man, fan.

In the primary series (Books 1-7), with a gradually increasing list of words and letters, the student must achieve competence in the following activities:

1. Sound-Symbol correspondence. The student is asked to pronounce the phonetic value of individual letters when written or to circle or write the appropriate letter when its sound is presented. (e.g., or "Write the letter for the sound /t/.")

2. Word discrimination. The student is asked to read aloud pairs of similar words or to choose one of a pair of words which is indicated by a picture. (e.g., "Read aloud, fan-pan." Or, if shown a picture of a fan and the words fan-pan he should draw a line under the word fan.)

3. Written programmed exercises. The student must fill in letters according to a reasonable pattern using pictures and past learning as a guide. (e.g., A picture of a fish is shown and the student must complete this sentence: A __ish has __ins.)
4. Dictation. The student is asked to write the first letter of each word in a list which is presented orally. (e.g., "Write the first letter of the word Sam.")
5. Reading aloud. At all stages the student is asked to read aloud stories using the words he has learned.

At the end of the primary series, the child has learned to read all regular consonant sound values and all "short" vowels. The rationale for the progression choices is to develop a rich reading vocabulary of words familiar to the child. To this end the author occasionally departs from the linguistic progression of Fries.

The following progression of topics is used for the second series of lessons (Books 8-14):

1. The student learns the long sounds for the vowels, sounds for double vowel, and vowel combinations.
2. The student learns the soft sounds for g and c.
3. The student learns the sounds for suffixes such as -le and y.
4. The student learns to read words with silent consonants.
5. The student learns the sounds for some other irregular subclasses of letter combinations.

Interface Requirements for Reading Instruction. From the above outlined sequences of objectives of instruction in reading, some properties of an instructional interface can be stated. The instructional environment must be able to present the individual letters in such a fashion that the student can be asked to discriminate between stimuli. Further, visual stimuli for the letter combinations must be presented to the student and the oral response of the student detected. Since the proper use of the student's entering vocabulary is important to a successful introductory reading program, the facility should have the means of detecting, recording, and providing instruction which is contingent upon the student's verbal behavior.

Almost all reading programs today contain instruction in phoneticizing. The student must make an approximate pronunciation according to some symbol-sound correspondence and then be able to identify a common word from the approximate pronunciation or have the approximate pronunciation shaped into the correct pronunciation. In order to deal with the problem of presenting examples of phoneticizing and to shape the student's approximate pronunciations there must be a sound display and detection capability.

In order to correct a misread or mispronounced word, voice-detection equipment must actually detect the words spoken and be able to compare the spoken word with the visual stimulus. Since most pronunciations are approximations of some standard or ideal pronunciation the instructional device must have the capability of accepting all responses within certain tolerance limits, rejecting all utterances outside the tolerance limits, and gradually decreasing the tolerance limits until a suitable final standard is reached. A sequence might be provided such that when a student mispronounces a word, the word would be correctly pronounced for the student and all other words removed from the visual display until the student has repeated the troublesome word correctly. The incorrectly pronounced words would be stored and displayed again to the student until he is able to pronounce them without error.

In the beginning stages of reading instruction a high degree of prompting is required. Both visual and auditory prompts will be needed. For example, an H built into a picture of a house can be used as a prompt for the name or the sound of the letter H. As the student learns the letter, the picture is gradually faded until only the letter H remains. An auditory prompt may be the direct auditory presentation of a sound with a letter and fading of the sound intensity as the student latency of response becomes less until finally the auditory prompt is eliminated.

In other stages of discrimination and response training less direct prompts will be used, e.g., a preceding word familiar to the student may be used to prompt the pronunciation of a subsequent word as in the following sentence: "The principle reason is that he is invincible." Here, the word principle prompts the similar pronunciation of invincible.

Latency of response to the visual symbols is an important factor in the pacing of prompts, introduction of new material, and an increased rate of presentation. For example, the final stages of reading instruction involve oral reading by the student with correction when a student error occurs. Textual material may be presented at a gradually increasing rate. If a difficult word causes a student to pause in his reading, a prompt may be employed to assist the student to respond. In both of the above situations (increase of rate of stimulus presentation and assistance when an error occurs) the key to appropriate changes in the environment is the student latency of response. Thus, the measurement of student latency is a desired facility.

In summary, the subject of reading requires that an interface have the following characteristics:

1. Visual display mode for letters and other visual symbols and pictures.
2. Response mode for the selection of graphic letters as responses and for the selection of graphic words as responses.
3. Voice detection mode which can determine whether a letter has been correctly discriminated and correctly pronounced.
4. Voice detection mode which can ascertain correct word pronunciation with a certain tolerance and measure and record the latency of the response.
5. Prompting provisions for the early stages of training and prompting provisions which depend upon the latency of response in the later stages of training.

6. Stimulus presentation of printed words which varies both in rate and word range with the student's prior performance.

Science

Science makes the greatest demands upon the interface in terms of the range of material (oscilloscope traces, spring arrangements, solids, liquids, gases, and much more) which must be presented, the range of manipulations which must be performed with these displays, and the range of student responses which must be accommodated. The two-dimensional display is used only in so far as the experience of the student has enabled him to abstract meaning from the multi-dimensional world which is the basis of the picture, the line drawing, or the model. A three-dimensional model is of greater use for the student because the degree of abstraction required is less than that needed when two-dimensional representations are used, and the model may offer possibilities for student manipulation which a drawing cannot offer unless extensive simulation techniques are used. But, in science, even three-dimensional models are sometimes unable to carry enough information to meet the needs of the student. For example, a model of a salt crystal using sticks and balls is used to show the relative position of atoms and the spacing of atoms in the crystal. A young student will not be able to use this model until some means is found for him to appreciate the idea of scale, the forces between atoms, the manner in which the shape of a large crystal depends upon the atomic arrangement and other ideas. The student requires a range of experiences with the properties of atoms in order to make the kinds of responses which are expected after even elementary instruction in the atomic structure of matter.

Laboratory Work. Virtually every educator who writes on the subject calls for increased contact with the phenomena of science. Curricula are built around demonstrations and laboratory work in spite of the difficulty in documenting the need for such student interaction (Brown, 1958; Nedelsky, 1958). Results in course examinations of students who have had laboratory sections are not significantly different from the results of those who have not had the experience. On the other hand, the difference in performance of boys and girls in physics is often attributed to the fact that the males are much more likely to have had the experience of manipulating erector sets, radio kits, tools, and other elements which give them experience related to the subject matter of physics. Stendler (1961) gives evidence supporting the above statement from a study of freshmen at the University of Illinois. Bruner (1960) says, "... The teaching aid has a function of helping the student to grasp the underlying structure of a phenomenon -- to sense the genotype behind the phenotype, to use terms from genetics. The well wrought laboratory experiment or demonstration is the classic aid in such activity" (p. 81).

Perhaps the need for demonstrations and laboratory exercises is obvious, but the manner of presentation and the time in the education sequence at which the exercises are presented is much in question. In Bruner's book (1960), Inhelder is quoted:

> ... It seems highly arbitrary and very likely incorrect to delay the teaching ... of physics, which has much in it that can be profitably taught at an inductive or intuitive level much earlier. Basic notions in these fields are perfectly accessible to children of seven to ten years of age, provided that they are divorced from their mathematical expression and studied through materials that the child can handle himself (p. 43).

One small piece of experimental evidence exists that may be used to show that the fault lies not with the laboratory work but with the way in which the laboratory work is conducted. Wall, Kruglak, and Trainor (1951) have shown that performance tests in laboratory work increase the effectiveness of the laboratory exercise. In the performance test the student had to make responses using the equipment without the step-by-step prescription that usually accompanies a student laboratory period. In order to reconcile the strength of the belief in the need for laboratory work and demonstrations with the lack of evidence that these activities help the student attain the goals of instruction, the following argument is offered:

1. Student response is either not elicited or is in a form which diminishes the learning value of the exercise (e.g., cookbook laboratory forms). Many studies and the words of many educators have pointed to the need for an appropriate student response to a stimulus if effective learning can take place. Out of the vast number of responses which a student may make to a classroom demonstration or to a laboratory exercise, some means must be provided for encouraging an appropriate response, noting which responses are made, and reinforcing preferred responses. Though many responses may be correct, it seems clear that merely sitting before a demonstration or filling in the blanks of a laboratory sheet are not the behavioral outcomes being sought -- especially when the procedure is outlined step by step and the desired numerical outcome is well known in advance.

2. The length of time involved in dealing with a single concept in conventional laboratory work is so long that the learning efficiency of laboratory work is low. Too often, emphasis is placed upon setting up of sophisticated equipment as a desirable end in itself. Setting up equipment may indeed be a desirable skill, but often almost the entire laboratory period is consumed in this activity and the important concept being demonstrated is lost in a rush at the end of the period. As a result, any insights or understandings gained in the exercise go not only unreinforced; they go unattended. Since the beginning student cannot always appreciate which observations are important and which are trivial, immediacy of reinforcement becomes an important tool in beginning learning. As the student becomes more sophisticated in a subject, he can formulate rules for determining the significance and correctness of an observation.

3. The laboratory and demonstration material is not being given to the student at the stage (elementary grades) in the student's development when it can do the most good in structuring the world for future learning. This follows from the argument of Inhelder and the results of Stendler which show that early experience with physical phenomena do result in enhanced academic performance in later years.

Lack of Consensus in the Elementary Curriculum. Except for nature study, health, and incidental work, such as accompanied the advent of the satellites and rockets, it seems safe to say that there has been no standard curriculum for science in the elementary grades. Recently, educators and scientists have begun to address the problem (Karplus, 1962; Rosenbloom, 1964; Seeger, 1959; Stahl, 1961; Pennsylvania Curriculum Development Program, 1963; AAAS, 1963). Consistent with the scope of present-day science, these experimental programs cover a wide range of subject matter, and no hint of consensus of educators has yet become apparent. Many educators still feel that formal science instruction in the traditional areas of physics, chemistry, biology, and geology should not begin until high school or perhaps even college. One argument runs that it is important to develop the processes involved in scientific inquiry at the elementary level rather than any particular content area. Exemplifying this point of view is the AAAS series of science activities called Science, A Process Approach. While there are those who oppose this point of view on the basis that if the student is taught the content his "natural powers of generalization" will enable him to use that content for the solution of problems, the inability to find an agreed-upon content has led to consideration of the behaviors which the elementary school student might learn in a program dealing with any science, be it astronomy, chemistry, biology, geology, or physics. The AAAS report (1963) considers the following to be the processes of science: observation, classification, recognition and use of space/time relations, recognition and use of numbers and number relations, measurement, communication, inference, and prediction.

It is noted that these processes cannot be taught without content, but the content is chosen more for its suitability in illustrating the process involved rather than for the importance of the content in the elementary curriculum. Nevertheless, an amazing amount of content in the AAAS series is apparently chosen to provide the student with the means of making the abstractions, visualizations, and generalizations which must be made when the student encounters a textbook presentation of science.

Behaviors Relevant to the Study of Science. For the purposes of this report a sequence of behaviors has been formulated which attempts to take into account the entering behavior of an elementary school student and which is sequential in that it builds toward ever more complicated and sophisticated behavior. The examples are deliberately scattered over the sciences in order to emphasize the fact that the instructional goals listed are intended to be applied to many areas of science:

1. The student should be able to make elementary discriminations in his environment and record these observations in his own words:

   Example: Green plants turn brown when deprived of water.

2. The student should learn to make quantitative measurements on his environment and record the results of his measurements in some orderly fashion.

   Example: Daily outdoor air temperature variation over the school year.

3. The student should learn to use instruments to extend his ability to observe and measure.

   Example: The use of the microscope to observe the living cell.

4. The student should learn to (a) determine the relationships between his observations and measurements and (b) use these relationships to solve a particular problem.

   Example: The use of a measuring cylinder to determine whether liquid in containers of different shapes have the same volume.

Instruction in more advanced phases of a subject is implied in goals 5 and 6 which follow:

5. The student should learn the content of the scientific disciplines, and they should learn that this knowledge enables a new range of problems to be solved.

Example: The relation between color and temperature to determine the temperature of an incandescent body.

6. The student should learn that mathematics must be applied to reduce difficult or complex problems to manageable form.

   Example: The use of the relation for centripetal acceleration to determine the orbital velocity of a satellite.

Interface to Provide Automated Science Presentation. It is the contention of this report that special need of elementary science instruction is interaction with the phenomena of the real (i.e., non-representational) world. What emerges is the need for an interface which can be used for automated science demonstration which involves student manipulation of the variables in the demonstration. For example, a lesson in electric currents should have a rheostat knob which enables the student to vary the current according to instructions. If an audio oscillator is part of the interface, there should be a control dial available to the student so that the frequency and intensity of the sound can be varied by the student as part of the lesson sequence. If the student is to observe the effects of temperature upon biological activity of a one-celled animal, the temperature control thermostat might be controlled by the student.

If the instructional goals are considered, the criterion which emerges is that the interface must be equipped to enable the student to experience a wide range of scientific phenomena which can be put into or simulated in a small space. If a specific lesson in physics, biology, etc. is considered, then a particular facility may be desirable. If some concept such as relativity is deemed critical, then a special purpose interface can be designed to enable the student to evolve the laws of relativistic motion through simulation of a world in which the speed of light is 10 miles an hour. In such a world, which might be simulated as a flight trainer simulates flight, as the speed of 10 miles per hour is approached, the surrounding terrain would be foreshortened, particles encountered would have greater and greater mass, and oncoming light would appear to be more and more blue.

The stimulus and response requirements of science seem to fall into two areas. In one area the need for laboratory manipulative experiences is so great, or the degree of simulation of experience is so complex, that a device designed to meet the requirements is highly specialized and unsuitable for use outside of a limited area of instruction. The device needed will be called a special purpose device for science instruction. (An example of a special-purpose interface is provided by the lesson on force in the appendix of this report.) The other area of science instruction has stimulus and responses requirements which can be met by commonly available stimulus and response devices; these will be called general-purpose interface devices for science instruction.

If the process approach is accepted, it is postulated that a general-purpose interface design using standard technical equipment would provide ample opportunities for interface instruction. With minor modifications the audio facility can provide a range of experiments in sound at the elementary level. The visual display can do the same for light. If an oscilloscope or television screen is part of the interface, it can be used to supply a visual display of sound phenomena; it can be used for programs in electricity and electronics and magnetism; and it can be used as a simulator of experiences, such as observation through a microscope, which normally involve only the sense of sight. Consider for concreteness a short example for each instructional goal listed above.

1. Elementary discrimination. When an intense visual projection is removed from the screen, a negative afterimage is seen.

2. Elementary quantitative measurements and record. Reaction time of each child in class detected by touch-sensitive screen after sound or sight signal.

3. Use of instruments to extend observations. Use of voltmeter to observe filament voltage.

4. Use of relationships between observation and measurements to solve problems. The problem may be the decrease in visual intensity of a TV screen as a knob is turned. The sensory observation is the decrease in visual intensity. The quantitative measurement is the filament voltage as displayed by a voltmeter. The (limited) solution to the problem is that the filament requires a minimum voltage to operate properly.

5. Relation between content and depth of solution to problems. If the student has learned about thermionic emission, he can infer that as the voltage is decreased the current through the filament is decreased and the current is no longer able to heat the filament sufficiently to cause an ample supply of electrons to be emitted.

6. Use of mathematics to handle difficult problems. If the student can perform the operation of squaring a distance and inverting the result, an oscilloscope screen or a TV screen in combination with a light of variable intensity could be used to enable the student to develop the inverse law of radiation intensity.

Summary. The history of elementary school science is too short and the subject matter is too varied to permit a listing here of curriculum areas relevant to an interface design. It is suggested that experiences with the phenomena of the natural sciences are important at an early age. An important reduction of the problem is possible if it is agreed that the development of a certain behavioral process in some areas of science are more important as an instructional goal than the study of any particular topic in science. This may be generally true even if certain specific topics turn out to be important enough to warrant universal inclusion in the elementary curriculum.

Summary of Subject-Matter Implications for an Interface

The subject matter of reading, science, and mathematics for the elementary grades has been considered in order to extract the stimulus and response provisions which must be provided for an instructional environment in each of these subjects.

Mathematics. The analysis of the elementary mathematics leads to the conclusion that visual display with the use of auditory stimuli for special purposes and for students who cannot read will handle most of the problems of instruction in mathematics. However, two major problems of instruction may require additional display modes. The first of these is the abstraction of the concept of number from arrays of objects. If the student has already established the use of pictures to represent objects, pictures of arrays of objects will suffice for instruction leading to the concept of numerosity. If this ability to use pictures is not well developed, successful instruction may depend upon the use of real objects to develop the concept of number and attaching a verbal response to problems involving number. Once this has been accomplished much instruction in mathematics can proceed by developing verbal-symbolic correspondences as in reading and by developing the properties of numbers according to the place value schemes.

The visual-auditory combination may fail when the student must make visualizations in three dimensions from a two-dimensional display using algebraic relationships. For example, a student must be able to make responses depending upon the relation that $x^2 + y^2 + z^2 = c^2$ represents a sphere. In two dimensions he can be shown that $x^2 + y^2 = c^2$ represents a circle and it is not too difficult to extend this relation to a sphere. Other relations between numbers and space are not so easily extended from the two-dimensional case to the three-dimensional case. For example, the use of altitudes, slopes and contour lines to describe the terrain of a map probably requires some specific experience with the three-dimensional terrain or a raised relief map in order to develop the ability to visualize the three-dimensional terrain from a two-dimensional map with contour lines. The use of two-dimensional graphs or maps, the use of purely symbolic description of a three-dimensional surface -- if they can be taught in the elementary program, -- would be an important prelude to the use of symbolic representations of many-dimensional space (as in statistical mechanics and relativity) as a generalization from three-dimensional space.

Reading. In the conventional instruction program, much of the entering behavior of a normal six-year old in our society is assumed for the purposes of instruction. Colors are assumed to be known. Common items are assumed to be familiar enough to be represented by pictures. In general, the speaking vocabulary is held to be sufficiently advanced so that instructions such as, "Put your X over the dog, " can be understood. For this entering behavior, a program with auditory and visual stimuli is sufficient for establishing the grapheme-phoneme correspondence which our review identified as an essential part of reading instruction. At an earlier age, the child's visual discrimination is not nearly as well developed as required by the reading readiness tests which are often given. In order to attach the problem of establishing the visual discrimination of the graphemes which is required, it may be found that multi-sensory stimulus will be necessary. Thus, textured letters, jigsaw puzzle letters, three-dimensional letters which can be held and played with, may be necessary for reading instruction. On the other hand, all that may be needed is clever programs which develop the visual discrimination through reinforcement of steps toward the correct visual discrimination.

Science. An attempt has been made to show that science requires special purpose devices which provide the stimulus and response displays for perhaps a single concept (e. g., mass) and more general purpose devices which can teach the content of an area of science through a combination of flexible manipulative devices such as audio oscillators, meters, and projection lamps, as well as more conventional display devices. By conventional displays is meant the projection of pictures, symbols, and auditory verbal information. A great deal may be accomplished through simulation in which a display simulates an environment in only some of the aspects of the real environment. An example was suggested of a simulator which could display the effects of relativity. The response provisions of a simulated environment can be purely electronic so that a wide range of physical phenomena can be simulated. In the simulated presentation of physical phenomena, many sensory experiences will be omitted (smells, unexpected sparks, the flavor of chemicals in one's mouth, the sensation of heat and cold and other aspects of sense of touch). It is not clear to what extent these omissions will interfere with learning. It may well be that the simulated experiences in combination with experiences outside of the formal learning environment will provide all the information for effective generalization and concept formation.

Interface Aspects and Instructional Requirements

Illustrative Instructional Procedures

The concern of the first portion of this chapter has been how subject matter properties influence an instructional interface. A further concern is the implementation of instructional procedures that can be provided by a flexible (computer-assisted) interface. To pursue this latter aspect, procedures that have been described in developing sequences in programmed instruction are discussed for illustrative purposes. The procedures considered are: (a) determination of entering behavior, (b) participation in terminal behavior, (c) generalization display, (d) gradual progression, (e) reinforcement, (f) prompt guiding of learning, and (g) withdrawal of guidance.

The above have been called procedures rather than principles to deliberately avoid the suggestion that they are all-inclusive or that the relation of these techniques to the learning process is firmly established by research in a wide range of learning situations. With this qualification, the manner in which an interface can provide for each procedure can be discussed. The final decision as to how much prompting and what kinds of reinforcement are desirable under each learning situation must be determined by practical experience and instructional research involving examination of the results of instruction. Here it only will be shown that a flexible interface can effectively apply these procedures in a way that provides a rich learning environment. For this purpose the areas of reading, mathematics and science will be considered.

Determination of Entering Behavior. In a simple case this means the determination of what the student already knows about the material which will be taught in the program. In a more sophisticated case the entering behavior of the pupil may be used to prescribe a course which is designed for his individual interests and abilities. If his behavior can then be monitored during instruction, adjustments can be made on the basis of continually accumulating information as well as the entering-behavior information. Entering behavior can be measured along many dimensions. A listing from Travers (1954) follows: (a) the extent to which the individual has already acquired the responses to be learned in instruction; (b) the extent to which the individual has acquired responses which are necessary "prerequisites" for learning; (c) the extent to which the individual has acquired "learning sets" which facilitate what is to be learned; (d) the extent to which the individual has the ability to make the kinds of discriminations, e.g., spatial, abstract, numerical or linguistic which are necessary to profit from instruction; and (e) the extent to which the individual has certain kinds of motivational and interest requirements as a result of his past history.

Participation in Terminal Behavior. This might be called "vicarious participation"; its purpose is to make certain responses more probable when they are required in the instructional program. The reinforcing property of terminal behavior competence may be useful in early instruction to reinforce student interest and to enhance motivation. In learning to ride a bicycle, for example, a good teacher often makes a point of letting the child ride the bicycle by himself during the first few lessons. In this case, by himself means that the teacher is holding up the bicycle from the rear. For the student, however, it is the terminal behavior he thought to engage in only after much practice. Being able to "ride a bicycle" just a few minutes after instruction has begun can be highly motivating and can provide a basis on which less dramatic behaviors can be built. In the same way, it is motivating for a beginning typist to type 60 words per minute although it may be the same word typed over and over. A simulated environment in which the student has the illusion of participation in the terminal behavior (diagnosing a disease, flying an airplane, solving a problem of scientific measurement) also appear to provide appropriate contingencies for both right and wrong responses, without the disastrous consequences which might occur in a completely realistic situation.

Similar to a simulated experience in the terminal behavior is the experience of watching or participating in a story with desired elements of behavior integrated into the story. Thus, a story in which scientific analysis provides the solution to a desperate problem, e.g., the development of a vaccine, might serve to make responses displayed in the story (self-discipline, use of subject knowledge, safety precautions, etc.) more probable as the student proceeds through an instructional program. A relevant statement is made by Bruner (1960) in discussing aids to teaching.

> Closely related to these are what might be called _dramatizing devices_. The historical novel that is true in spirit to its subject, the nature film that dramatizes the struggle of a species in its habitat, the exemplification of an experiment executed by a dramatic personality ... all these can have the dramatic effect of leading the student to identify more closely with a phenomenon or an idea. Undoubtedly, this "aid" in teaching can best be exemplified by the drama-creating personality of a teacher. But there are many additional dramatic aids upon which teachers can and do call -- and one wonders whether they are called on enough (p. 82).

Generalization and Discrimination (Concept Formation). Generalization refers to the fact that a student learns to respond to similar elements in different learning situations. He learns, for example, to recognize that all words with certain characteristics belong to one class called nouns, or that mammals belong to a class called vertebrates and many other creatures belong to a class called invertebrates. In addition to responding to similar elements in different situations, an individual also learns to make appropriately different responses to different stimulus situations. For example, he learns to discriminate between nouns and verbs. When a young child, on the right occasions, says _dog_ and _cat_, he has learned to discriminate between these two classes of animals. When he calls a strange cat that he has never seen before by the right name, or when he says the word _cat_ to the picture of a cat or to the sound of a cat purring, he has generalized within the class of stimuli that have to do with cats. When an individual has learned to make discriminations so that he can respond selectively to different stimuli, and when he has learned to generalize these same responses to a variety of situations, he has learned the concept. In the same way that the child learns the class concept cat and dog, the older child learns the class concepts noun and verb, and the still older child learns the concepts light and sound.

Gradual Progression. The principle involved here is that the program of instruction must progress gradually so as to minimize wrong responses. The integration of this principle with procedures for the use of errors as effective learning experiences appears to be the efficient course for an instructional progression. In general, however, to obtain a reasonable rate of progress toward an instructional goal, the material preceding a display must have the elements which will permit a fair and challenging chance to make correct responses. Classical or expected errors may then be dealt with by a branched set of items which are themselves arranged in a gradual progression toward an instructional goal. An aspect of a permitted error rate is that certain items can be used for diagnostic purposes. The quick student who masters these diagnostic questions proceeds through the program more quickly. The student who misses the diagnostic items is provided with the additional steps required for mastery.

Reinforcement. Certain stimuli contingent upon the occurrence of a response may make the response more likely to occur in the future. In the case of human learning, the determination of reinforcing stimuli is an important element in the development of an instructional interface. Reinforcers may be extrinsic (money, a gold star, approval) or intrinsic (related to subject-matter attainments such as getting the correct answers, solving a challenging problem, developing increasing competence). In general, intrinsic reinforcers are preferred when they are effective, since extinction of responses may occur when extrinsic reinforcement is withheld. From the practical point of view it is efficient not to need a complicated system of awarding reinforcers. If extrinsic reinforcers are required, the interface can be programmed to award them on the appropriate schedule for the degree of persistence of response which is desired at a given learning stage. A major advantage of a flexible interface may be the provision of intrinsic subject-matter reinforcements which result from the student's ability to freely manipulate and modify subject-matter properties.

Prompting and the Guidance of Learning. There is discussion in the current literature of learning technology concerning the relative merits of various prompting procedures. In general, it seems clear that in many stages of instruction, efficient learning requires a hint or guide to the appropriate response to be learned. Where possible, a prompt which can be used as a mediator in future learning is to be preferred to prompts which are unrelated to future tasks. For example, a picture of an apple is a prompt to the sound of a letter a, and a phoneme for the letter a can become a prompt for response differentiation of the visually presented letter a. Depending upon the reading program both of the above prompts can be useful in future instruction sequences. On the other hand, an example of a prompt which may be unrelated to future learning in reading is the practice of putting significant letters (silent e, for example) in different colors from the other letters.

The interface environment can provide a wide range of prompts and procedures for guiding the learner. In reading, a word which a student finds difficult in pronouncing can be prompted by having the syllables spread apart on a screen, by having the word become larger in relation to the surrounding words, or by having a voice pronounce the first syllable. In mathematics, a numerical answer can be prompted by the appearance of a number of objects in a visual display, by a faint dotted outline of part of the numeral, or by the breaking down of a difficult problem into a more simple problem. For example, by the use of the distributive law and the idea that numbers have many names, the answer to the problem $7 \times 8 = 56$ can be prompted by the form:

$$7 \times (4 + 4) = (7 \times 4) + (7 \times 4) = ?. \quad \text{(Answer: } 28 + 28 = 56\text{)}$$

Withdrawal of Guidance. By the "fading of prompts" is meant the gradual elimination of a hint or cue which leads a student to the right answer. For example, if a house is built around the letter H as a prompt for the sound of H, the prompt may be faded in successive presentations by gradually eliminating parts of the drawing of the house until the student is able to respond when only the letter H remains. The need for guidance can be detected by the time it takes for the student to respond after the presentation of a stimulus. If a student is reading, a delay in pronouncing a word may indicate that he needs a prompt such as having the first letter or symbol pronounced. The latency of response is a guide to both the need for a prompt and the rate at which a prompt should be eliminated or faded. As the time between stimulus and correct response becomes shorter, the intensity of the prompt can be decreased until a quick response is available when no prompt is present: the troublesome word becomes displayed almost identically with the rest of the text; the breakup of an arithmetic problem into simpler steps is only hinted at; the prompt for a numeral in a problem becomes barely visible.

Sample Lesson in Mathematics

Consider a lesson in extending the understanding of the number system from 20 - 99. A projected instructional interface for this lesson will be examined for the manner by which it can include procedures outlined above. The terminal behavior being sought here is the ability to use the decimal number system in the range 0 to 100 in the following ways: (a) to be able to state X groups of ten is X, e.g., four groups of ten is 40; (b) if shown X groups of ten the student will say "X-ty"; (c) if asked, "If you put one more group of ten with 40, you will have ________?" he will respond, "50"; and (d) if shown XY, the student can determine that this means X tens and Y units.

Determination of Entering Behavior. The entering behavior required for this lesson is the ability to count to 100, the ability to group "things" into groups of ten, the ability to exchange ten objects for a ten-bar, and the ability to represent the number property of one to nineteen objects by a numeral in the decimal system.

To determine whether the student can count to 100, the student is asked orally (or by a printed command if he can read) to count to 100. The appropriate response is either to select in sequence, by pushing elements of a visual display, the numerals from 1 to 100 or to say them aloud. (The entering behavior in terms of the ability to read and write then becomes the first part of any examination.)

To test the ability to group things into a group of ten, the student may be given a large supply of discs and be asked to place one group of ten upon a table. Assuming that the student has learned that a ten-bar represents ten objects and that he is familiar with the word "ten-bar", an instructional interface must have the following additional capabilities: dispenser to present the student with 10 discs or other objects, a sensing device to verify that 10 discs are before the student, a supply of ten-bars, a means of determining that the 10 discs have been removed and that the ten-bar has replaced them.

To test the understanding of the numbers from 1 to 19, the student must be given the auditory or printed command, "Choose the picture with fourteen thing" or "Take fourteen discs and place them upon the table" or "Make fourteen by using a ten-bar and four discs." The response will then be detected by the selection of the correct picture or by the measurement of the objects which have been placed upon a surface.

Participation in Terminal Behavior. The student may be presented with arrays of objects, arrays of objects arranged in groups of ten, arrays of objects with a ten-bar for each group of ten. The student has a single choice control before him which may be called an activation button. If he activates the control, he is told something which will become part of his terminal behavior. For example, if there are seven ten-bars and three additional objects, when the control is activated the student is presented with either a visual display (73), an auditory display ("seventy-three"), or the replacement of the seven ten-bars by seven groups of ten discs. This presentation may take place as part of a story so the activation of the control comes in response to a question in the story such as "What number (numeral) do we write now?" The idea is that by talking to the student as if he is part of the story, he may identify himself with the operations which are being displayed each time he pushes the activation button. This technique requires a means of presenting a story, which involves various number tasks and which can be stopped while awaiting student response.

Generalization Display. Numerals must be presented in various type styles, including handwritten symbols. Arrays of objects must use a wide variety of objects: discs, trucks, horses, men, dots. Arrays of objects must be displayed in various geometric arrangements: squares, triangles, random arrangements, three-dimensional arrays. Various kinds of grouping must be employed: fourteen may be displayed as ten grouped discs and four additional discs, one ten-bar and four additional discs, fourteen neatly arranged discs, and fourteen scattered discs. Various visual and auditory equivalent stimuli and response can be employed: the student can be asked, "Find fourteen things," "Find enough discs to make one ten and four ones," "Find enough red discs to match the number of black discs on the table." On the other hand, a similar variety of visual commands (sound, command with visual display of numeral) may be given using the arabic numerals, the printed words for the numbers, or arrays of dots to represent a number of objects. Responses may be required for which the student supplies a numeral for a number of objects as well as a number of objects for a numeral.

Gradual Progression

1. The student counts objects to 100 by ones. An array of dots is added to the display such that a dot appears for each object counted and the dots are grouped by tens each time an additional ten objects are counted. For example, if forty-three objects have been counted, the numeral 40 would appear under four groups of ten, and the numeral 3 would appear under the additional three dots.

2. The student counts arrays of dots or objects which are arranged in groups of ten.

3. The student matches groups of ten.

4. The student is presented with an array of objects in groups of ten and determines how many groups of ten there are.

5. The student is presented with many groups of ten and circles a certain number of groups, as directed.

6. The student is given a number of objects and asked how many groups of ten he can make. Each of the steps 3-7 is initially a problem with exact multiples of ten and then with an additional number of ones.

7. The student is shown the numeral 20 and told that the 2 tells the number of tens. He is asked to find the two tens in a multiple choice problem of arrays of dots.

8. The student finds the number of tens in an array when presented with only the numeral. "When you are shown 30, find the box with the correct number of tens."

9. When shown a number of tens in array, the student selects the numeral which gives the correct number of tens.

10. Steps 8-10 are repeated with elements in the unit's place.

Reinforcement. On an appropriate schedule, reinforcement can be provided after certain responses by supplying particularly attractive and novel items for the object arrays of subsequent problems. Other appropriate reinforcements are: (a) the opportunity to play number games related to the lesson, (b) the awarding of attractive pictures illustrating some of the relationships which have been learned, (c) the opportunity to choose to skip a certain number of steps in the instructional process, and (d) extrinsic praise and symbols of achievement.

Prompting. Overt instructions may be provided which do not supply the answer. For example, if the student must group objects by ten, he can be asked, "Can you make one group of ten? ... Now can you make another group?" The key to the need for such prompts is the student's activity or lack of it. Where a visual display is to be selected as a response, the intensity of presentation can be altered to make the correct element more likely to be chosen by the student. In rare instances the correct response to a projected problem can be presented in a prior statement, i. e., the student can be informed that 25 represents two tens and five ones prior to a problem in which two groups of ten objects and five additional objects is intended to call forth the response 25. (This type of prompt must be used with discretion because some students will pick up the ability to use the cue without an analysis of the problem.)

Withdrawal of Guidance. The prompts described above help the student to understand what kind of response is required and make the correct response. As soon as the student becomes familiar with the kinds of responses required, the prompts which assist him to make groups of ten can be withdrawn. As soon as the latency of response is short or the frequence of error is low, such cues to the correct answer can be used only when the student fails to respond within a certain period of time or when the student makes an error. In the latter case, the use of a prompt after an error may have value as an overt correction of an incorrect response.

Summary

The consideration of instructional procedures leads to additional stimulus and response requirements for the instructional environment. These additional requirements are: (a) the detection of student behavior -- such as vocabulary used, number usage in play, preference for certain activities, (b) the presentation of a simulated or controlled experience which enables the student to participate in the terminal behavior being sought, (c) the presentation of a wide variety of stimuli for a concept which must be generalized and the presentation of stimuli which define the limits of acceptable generalization, (d) the presentation fo stimuli in either a progression which is known to be effective in leading the student to the terminal behavior or in a progression which has branch points for anticipated student problems, (e) the occurence of reinforcing stimuli, (f) the presentation of guiding stimuli, and (g) the provision for withdrawing the guiding stimuli.

Possibilities of a General Purpose Student-Subject-Matter Interface

This section will consider the similarities among subject areas which may make feasible a single instructional interface which can be used to teach in such different subject areas as mathematics, reading, and science.

The differences among subject areas which will necessitate special interface devices will also be discussed. The basis for the conclusions is the analysis drawn from this chapter. From the stimulus and response requirements of the subject matter and of the instructional procedures a judgment can be made as to the properties of a single instructional device which could be used for instruction in subjects which seem to have little in common. This judgment is influenced by what seems to be technologically reasonable, but no attempt has been made to restrict the ideas to the hardware currently available.

Basis for Estimating Subject-Matter Range of General Purpose Interface

Even if the environment presented only visual stimuli, much as a book does, the logic which unites the stimulus to the student's response would put the device into a different class from books with paper and pencil responses. Thus, it is meaningful to ask what is the range of applicability of an interface with given stimulus and response provisions. For example, with only visual stimuli and a keyboard for responses, instruction may be provided for all students with a certain entering behavior (not necessarily ability to read) in such widely diverse areas as reading instruction, mathematics, science, as well as subjects such as history, literature, art, engineering calculations, and experimental techniques in science.

It is clear that sometimes a visual display with a touch-sensitive response display will not suffice. Three dimensions of the problem seem to be of major importance.

1. The entering behavior of the student determines many of the stimulus and response characteristics which an interface must have in order to provide instruction. For example, a visual display of magnetic experiments may be meaningless to a young student who has never experienced the ways an actual magnet interacts with magnetic and non-magnetic materials. However, a student with a history of experience in related areas could be instructed in magnetism by a visual display alone. At this point

the question of instructional efficiency enters. Efficiency is here defined as instructional time to terminal behavior for students who begin instruction with equal entering behavior and equal abilities. Thus, while almost any predominantly intellectual subject may be taught with purely visual displays, the end result may be accomplished much more quickly and easily with appropriate displays and manipulative features other than visual ones. In general, but not always, the less advanced a student is in a subject, the greater will be the need to utilize a wide range of display and response modes.

2. The subject matter determines other stimulus and response characteristics which the interface must have. While many things about violin playing may be taught by visual display with keyboard responses, most of the instructional time must be employed developing the psycho-motor skills required. Thus, either a violin or elements which develop the skills of violin playing would be required as part of an instructional environment. The extent to which the subject matter requires a combination of sensory and motor responses is the second dimension of analysis for the determination of the stimulus and response provisions of a general purpose interface.

3. The instructional requirements for effective learning will influence the stimulus and response provisions of the interface. If guidance is needed to teach a certain response, the stimuli to provide that guidance will have to be incorporated into the interface design. For example, if the student is to select a letter from an array of letters, and good instructional practice

indicates that the letter to be chosen should be made more prominent during the initial stages of instruction, a means of backlighting the letter may be incorporated into equipment design.

Hierarchy of Stimulus and Response Provisions

Visual and auditory display systems clearly rank highest for the purpose of a general purpose interface. In addition to the matter of presenting pictures and verbal information, each of these two display provisions can be used to present information ranging over a tremendous range of subject matter and student entering behavior. Time can be introduced through pulsed sound and visual display. Analogies can be developed through animation. Simulation can be developed through response of the display to the student behavior. Aspects of science can be developed not only through the display, but through the inherent technological elements of the display, e.g., a magnet brought close to an amplifier tube will change the level of sound and illustrate an item of instruction relating to the gain of a vacuum tube. Through polarized light displays or two-color displays, depth can be simulated. Physiological phenomena involving sensory perception can be illustrated along dimensions of pitch, flashing light frequency, optical illusion, fatigue, attention, stimulus intensity, etc. Almost all subjects have been attacked at some level by audio-visual instruction methods. The addition of logic between the stimulus and the student response so that further displays are contingent upon the student responses will greatly enhance the instructional possibilities of an interface with auditory and visual displays only.

Response Elements for a General Purpose Interface

The most flexible response facility envisioned as a result of the stimulus and response analysis made here is a touch-sensitive display. By this is meant an array of elements such that a wide variety of symbols can be projected upon the elements. When a symbol is touched, environmental changes occur which are controlled by the logic circuits of the device. A response element might have a color, a letter, a number, a mathematical symbol, an electronic symbol or a picture projected upon it. In many cases the response elements may also serve as the visual stimulus for the student. Response would usually be made by touching an element, but other means of activation, such as light pen, are feasible. Thus, a touch-sensitive display can provide for multiple choice responses, discrimination responses, solution of number problems, or manipulation of the original stimulus display according to some rules. The limitations of the use of the touch-sensitive response display would seem to lie in the student's ability to be instructed in its use and the limitations of time, i. e., it may take so long to generate certain responses by a touch-sensitive display that instruction may become uncertain. For example, a touch-sensitive display with discrete elements might be an awkward means for drawing a smooth curve. On the other hand, the ability to change the symbol in an element by a switch may reduce the time to form an answer. For example, if the symbols can be changed from letters to arithmetic numerals, the fact that a touch-sensitive display is used may make the generation of responses to arithmetic problems easier than would be the case for hand-written responses.

Limits of a General Purpose Instructional Environment

To be considered are the aspects of mathematics, reading, and science which require special purpose instructional devices.

Mathematics. The limit of the general purpose instructional environment depends upon the extent to which the student should manipulate objects to develop mathematical principles. The student may make an array of 3 x 4 and 4 x 3 objects to illustrate the commutativity of multiplication. This principle may be taught equally well by manipulating sets of objects on a screen with a light pen or by making arrays of pictures light up on a touch-sensitive display.

In another problem the student identifies geometric objects such as cubes, cylinders, spheres, and cones. At some stage of education it may be important to use the actual three-dimensional objects for instruction and an attempt to make a lesson conform to the format of a touch-sensitive display may result in an awkward sequence. For students with a different history, a touch-sensitive display using realistic photographs of these objects may be sufficient.

Finally, the various branches of geometry require line drawings to be constructed by the student, e.g., bisect the angle using your compass and straightedge. The technological means of providing this facility in a general purpose interface is not clear. Thus, the use of a Rand tablet or some other device which would permit the student to make the line drawings would seem to fall into the class of special purpose devices.

Reading. The general purpose environment outlined in this section would not have the means of detecting the responses in oral reading. In the early stages of reading instruction, oral responses must be detected and compared to the printed words that the student is reading. For this purpose the ability to detect a limited vocabulary of oral responses as made by a particular student is required. Thus, if a program cannot be devised which does not circumvent the need for detecting oral responses, either human instruction or a special device to detect oral responses would be required.

Science. The limits of the general purpose interface in the area of science depends upon the extent to which simulation and verbal instruction using pictures and line drawings can substitute for experiences with the actual phenomena. For example, it is not clear whether the concept of mass can be taught to a young student without the use of experiments with objects of varying mass, but the importance of having the experience occur during the lesson may justify the creation of special devices to teach certain basic concepts in science through the manipulation of a restricted range of phenomena.

In summary, an interface which supplies visual and auditory stimuli of the conventional audio-visual type (slides, tapes, video-tape, motion pictures or other) united by logic circuits to response provisions of a touch-sensitive display will serve to teach a wide range of students in a wide range of subjects. Flexibility can be accomplished by storing display elements by some means and altering the displays for different areas of instruction. However, each subject area will have some desirable lessons which cannot be taught effectively by the general purpose interface and which will require special stimulus and response provisions.

References

American Association for the Advancement of Science. *Science: A process approach, Part 4*. Author, 1963.

Brown, S. C. Do college students benefit from high school laboratory courses? *Amer. J. Physics*, 1958, *26*, 334-337.

Bruner, J. S. *The process of education*. Cambridge, Mass.: Harvard University Press, 1960.

Buchanan, C. *Programmed reading*. New York: Sullivan Associates, McGraw-Hill, 1963.

Carroll, J. B. The analysis of reading instruction: Perspectives from psychology and linguistics. In E. R. Hilgard (Ed.), *Sixty-third yearbook of the National Society for the Study of Education, Part I: Theories of learning and instruction*. Chicago: University of Chicago Press, 1964. Pp. 336-353.

Hawley, N. & Suppes, P. *Geometry for primary grades*. San Francisco: Holden-Day, 1960.

Karplus, R. Beginning a study in elementary school science. *Amer. J. Physics*, 1962, *30*, 1-9.

Markman, A. The Bloomfield-Barnhart approach to beginning reading instruction. In D. L. Cleland (Ed.), *New dimensions in reading: A report of the Nineteenth Annual Conference and Course in Reading*. Pittsburgh, Pa.: Herman Printing, 1963. Pp. 69-83.

Nedelsky, L. Introductory physics laboratory. *Amer. J. Physics*, 1958, *26*, 51-59.

Pennsylvania Curriculum Development Program. *Science in action: A guide for teaching science*. Harrisburg: Department of Public Instruction, 1963.

Rosenbloom, P. C. The laboratory: its activities, its record, its plans. *News Bulletin of the Minnesota National Laboratory*, 1964, *1*, 4-5.

Seeger, R. J. Physics for the first grade. Amer. J. Physics, 1959, 27, 494-500.

Stahl, F. Preschool physics. Amer. J. Physics, 1961, 29, 579-582.

Stendler, C. B. Cognitive development in children and readiness for high school physics. Amer. J. Physics, 1961, 29, 832-835.

Travers, R. M. An inquiry into the problem of predicting achievement. AFPTRC-TR-54-93. Lackland Air Force Base, Texas: Air Force Personality and Training Research Center, 1954.

Wall, C. N., Kruglak, H., & Trainor, L. E. Laboratory performance tests at the University of Minnesota. Amer. J. Physics, 1951, 19, 546-555.

Wirtz, R. W., Botel, M., and Sawyer, W. W. Math workshop for children. Chicago: Encyclopedia Britannica Press, 1961.

CHAPTER III

INTERFACE EQUIPMENT CONSIDERATIONS

Preface

This chapter will concern itself with visual and auditory information input channels, response output and the technology available for using these capabilities. Physiological and human factor considerations are briefly reviewed, but the emphasis is on the techniques available for utilizing these human capabilities in the educational environment. The scope of coverage is intended to include presently available devices, technically feasible devices, and potentially available devices. Some devices in the latter two categories may be financially impractical, but are included for research considerations and their possible long-range applications.

In general, cost and availability data have not generally been included because of the dependence of such information on quantity and market considerations when equipment is commercially available. Also, much of the equipment discussed is of a prototype nature and cost data is usually not known and cannot be accurately estimated. Specific sources of supply are mentioned only in those cases where the designation of the manufacturer aids in describing the equipment or otherwise serves as a reference to more information. In general, the bibliography serves as the directory to further exploration of any particular item discussed. The discussion of equipment in this section is not intended to be exhaustive or to serve as a listing of available equipment, but rather to indicate the possibilities that exist and the development work in progress that can contribute to the implementation of an experimental, and eventually operational, educational environment.

Visual Communication

In order to meaningfully consider visual displays, the basic characteristics or capabilities of the visual channel (the eyes) might be briefly reviewed. These capabilities concern light, space, and time. The light capability of the eye includes both sensitivity and discrimination of brightness. The relationship between brightness of an object and its background is called brightness contrast and is expressed as a percentage by calculating ($\Delta B/B$) x 100 where ΔB is brightness difference between object and background and B is background brightness. Contrasts of about 30:1 are preferable in black and white displays.

Spatial discrimination includes the four categories of visual acuity, depth discrimination, form discrimination, and movement discrimination. Visual acuity is a measure of the eye's ability to detect the

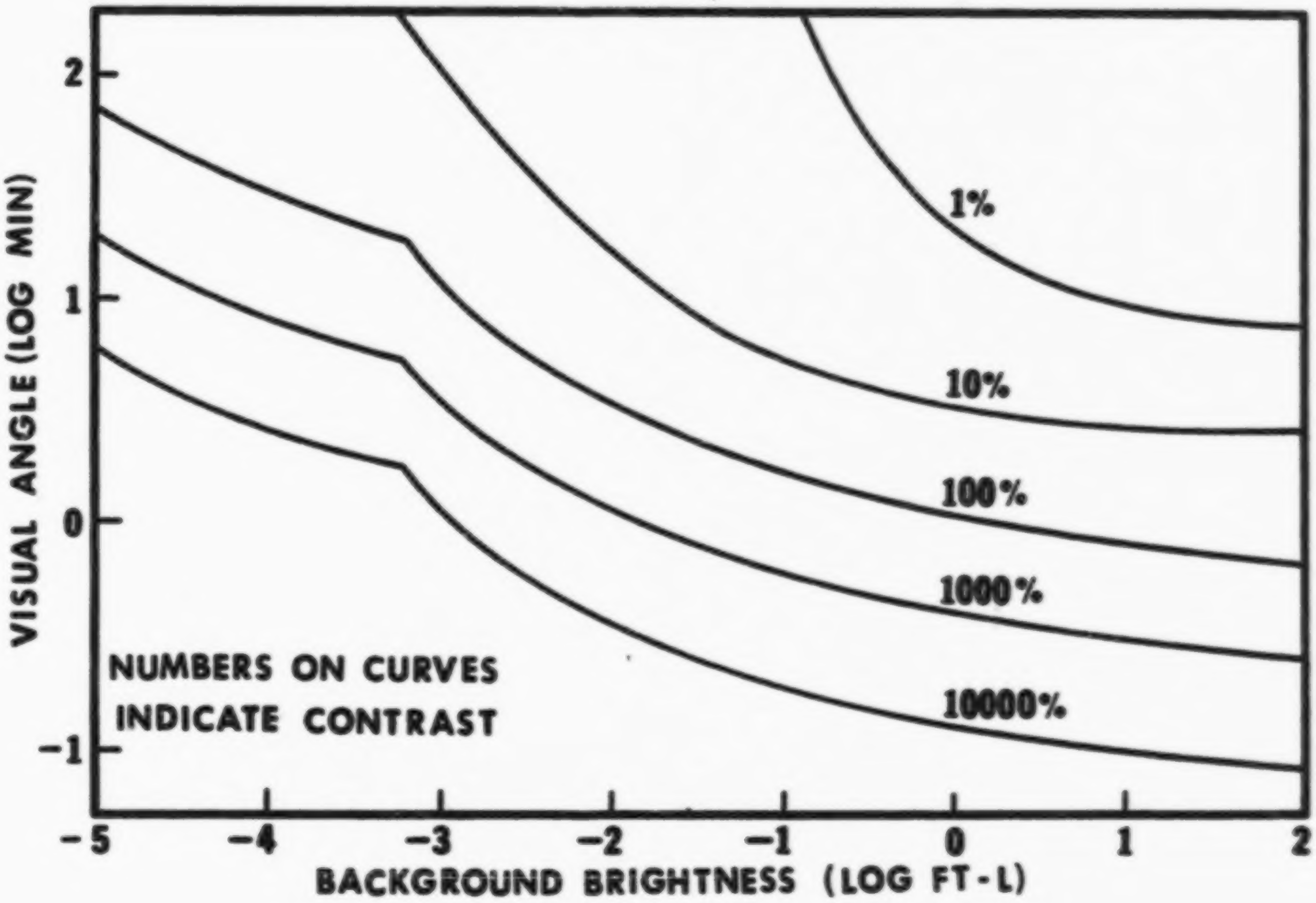

Fig. 3.1. Brightness Level and Contrast
(Morgan, et al., 1963, p. 60)

smallest target. It is defined as the reciprocal of the just resolvable visual angle measured in minutes of arc. With light spectral energies in the photopic region (5000-6250 Angstroms) the visual acuity varies between 0.5 and 2.0 depending on illumination intensities (Shalaer, 1937). Visual detection, however, depends both on brightness level and contrast as shown in Figure 3.1. The curves labeled 1% to 100% are for targets that are either brighter or darker than their background. The curves for contrast above 100% are only for targets brighter than their backgrounds. The thresholds in the figure are for 99% probability of detection which is almost certain detection. Visual acuity as a function of brightness of task area and immediate surrounding area is illustrated in Figure 3.2.

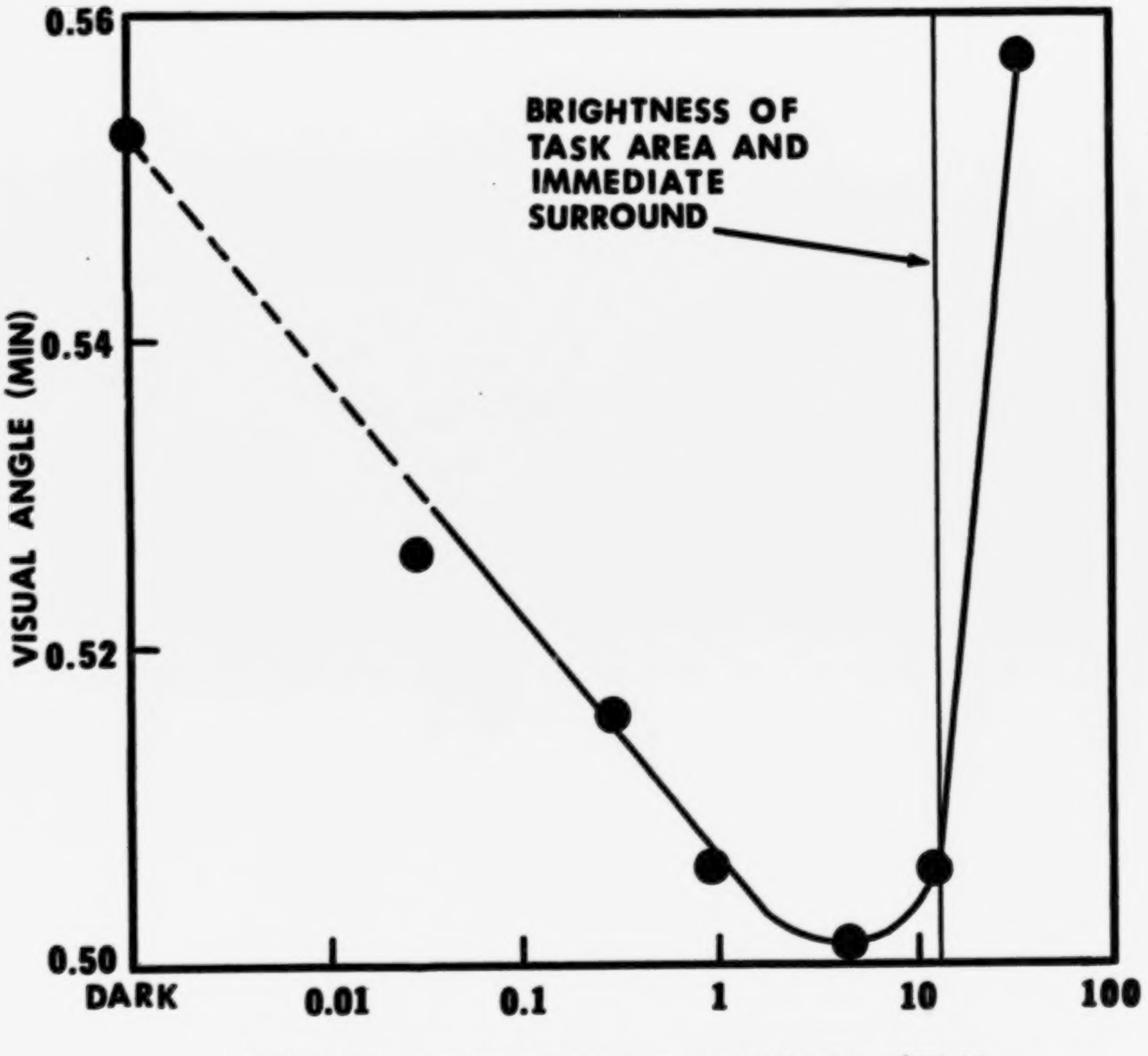

Fig. 3.2. Visual Acuity as Function of Brightness of Task Area (Morgan et al., 1963, p. 62)

Depth discrimination makes use of many cues with the principal ones, at least for objects within 2500 feet, being those resulting from binocular vision such as muscle tension to accomplish focus. Form discrimination utilizes visual acuity together with stored information regarding form with the principal cues being boundaries and shape. Movement discrimination is defined as the slowest perceptible rate of movement of the stimulus.

The ability to discriminate time is limited by the response time-lag of visual channel stimulation which varies from 0.05 to 0.4 seconds dependent upon color and intensity of stimulus. If a pulsing light is displayed with increasing pulse repetition rate, a point will be reached where the observed flicker disappears. This is often called the critical flicker frequency. Figure 3.3 illustrates the dependence of flicker threshold on brightness and duty cycle (percent of time light is on).

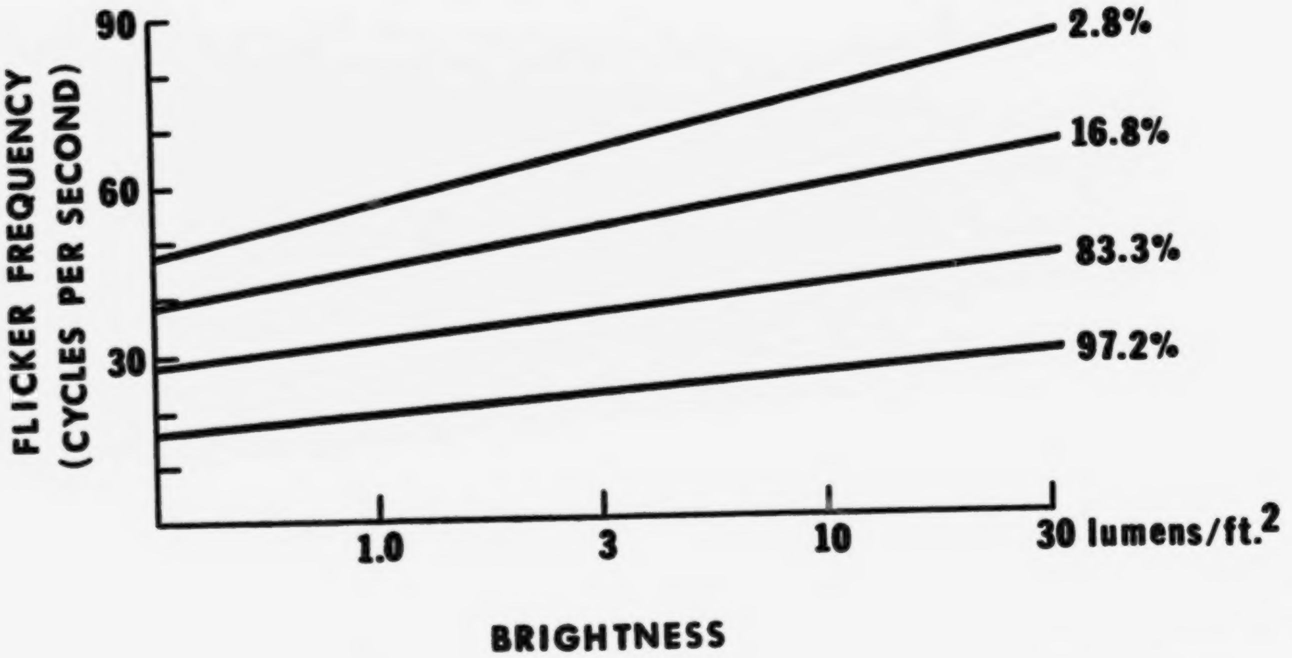

Fig. 3.3 Relation of the Threshold Frequency of Flicker to Brightness (Zworykin & Morton, 1954, p. 188)

Other factors of significance to visual displays are display response times and display configuration. The response time is the time interval between the initiation of action to cause a display change and the actual change of display. This time can be a function of many factors such as queuing load on equipment involved, erase and write times of display used, and processing time required to create new display information.

The primary consideration of display configuration is size and shape. Experiment and moving-picture experience show that with a picture having a vertical to horizontal dimension ratio of around 3:4, the vertical dimension should not subtend a vertical angle of more than 15 degrees. Such an angle permits obtaining a more or less simultaneous impression of the entire content of the display and examining in detail all points simply with motion of the eyeballs and not the head.

Coded Displays

Perhaps the simplest displays from a control and implementation viewpoint are the coded displays such as lights, mechanical indicators, and keys. This type of device is completely adequate when messages of low information content are to be transmitted. For example, feedback information concerning correctness of a response is often of this nature and consists of one or two colored lights mounted on the response device. The code or "meaning" of displays of this type must be easily understood by a user and generally limit the amount of information such a device can display. Figure 3.4 illustrates the general shape of the curve which plots percent errors as a function of number of symbols or code complexity. There is no scale on either coordinate because exact metrics depend on type of code (color, shape, size) and the conditions under which it is used. However, the important thing about the curve is its general shape which indicates that severe penalties in accuracy are encountered when too much information is packed into such a display. A "rule-of-thumb" may be to use only as many symbols in a code as are absolutely necessary.

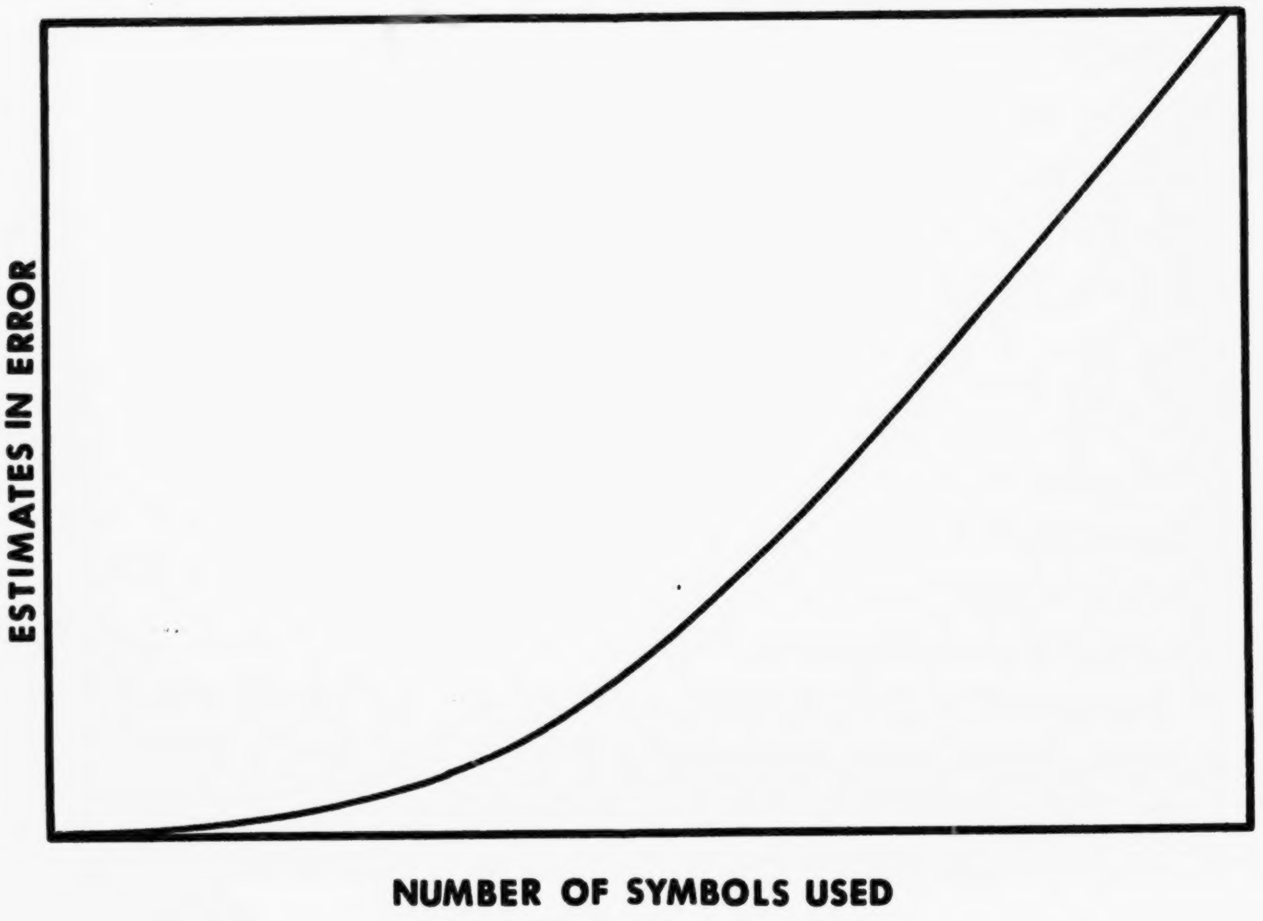

Fig. 3.4. Relation of Errors to Number of Symbols
(Morgan et al., 1963, p. 90)

The most common codes used in devices of this type are obtained through the use of colors, shapes, or alpha-numerics. With color codes the use of colored lights is usually preferred to paints or reflected colors since colored lights are not affected by the color of the general illumination as much as surface colors. A normal person can correctly identify around ten spectral colors when the brightness is one millilambert or more and the visual angle is 45 minutes or more. When shape coding is used, the shapes should generally have high association value with the subject matter or else be highly discriminable between shapes. About fifteen different shapes can be reliably distinguished when the outline is sharp, the contrast high, and the visual angle at least twelve minutes.

When alpha-numerics are used as with keyboards or for printed displays, they should have high contrast, sharp outlines and subtend a visual angle of at least ten minutes.

Film Projection Devices

The application of film projection devices for educational purposes has been used for a period of time that makes it unnecessary to elaborate the capability or potential of such devices. These devices can still produce the best quality and greatest range with regard to such parameters as size, brightness, contrast, resolution and color tone. Also, film is a medium of high information storage density, and although much of the information stored on pictures may be redundant, it is not likely that other practical techniques will soon surpass film on the basis of information stored per unit volume. This very characteristic of storage, however, causes film displays to be basically predetermined or stereotyped, and no new or previously unconceived display can be presented as a consequence of some response. Films can be selected as the result of a response, but the selection must generally be available in a file of possible alternatives.

Selection With Fast Access. Techniques for acquisition of information within a few moments exist in present day devices such as the U. S. Industries Autotutor and the Thompson Ramo Woolridge Mentor. These devices generally have a selection limited to frames that are judiciously located with respect to the frame being displayed or else the access time becomes significantly longer. Techniques have been developed with military and other display systems, however, that provide an access of a second or less to any one of several hundred frames.[1] This capacity could be increased through the use of parallel units although the cost and complexity of such systems would increase in an exponential manner.

---

[1] Observed on personal visit to Hughes Aircraft, Fullerton, California.

Real-Time Created Displays. Displays which are a function of the student's responses or actions and which utilize film can be simulated or approached by several techniques. One method is to superimpose symbols on a film projected background. This is often accomplished optically by having a program or input-controlled mirror position one or more high luminosity spots with respect to a background display. This is analogous to the lecturer who uses a light pointer for drawing attention to items on a chart or slide presentation. The schematic of such a technique is illustrated in Figure 3.5, where the position of the mirror can be both controlled and sensed by the program.

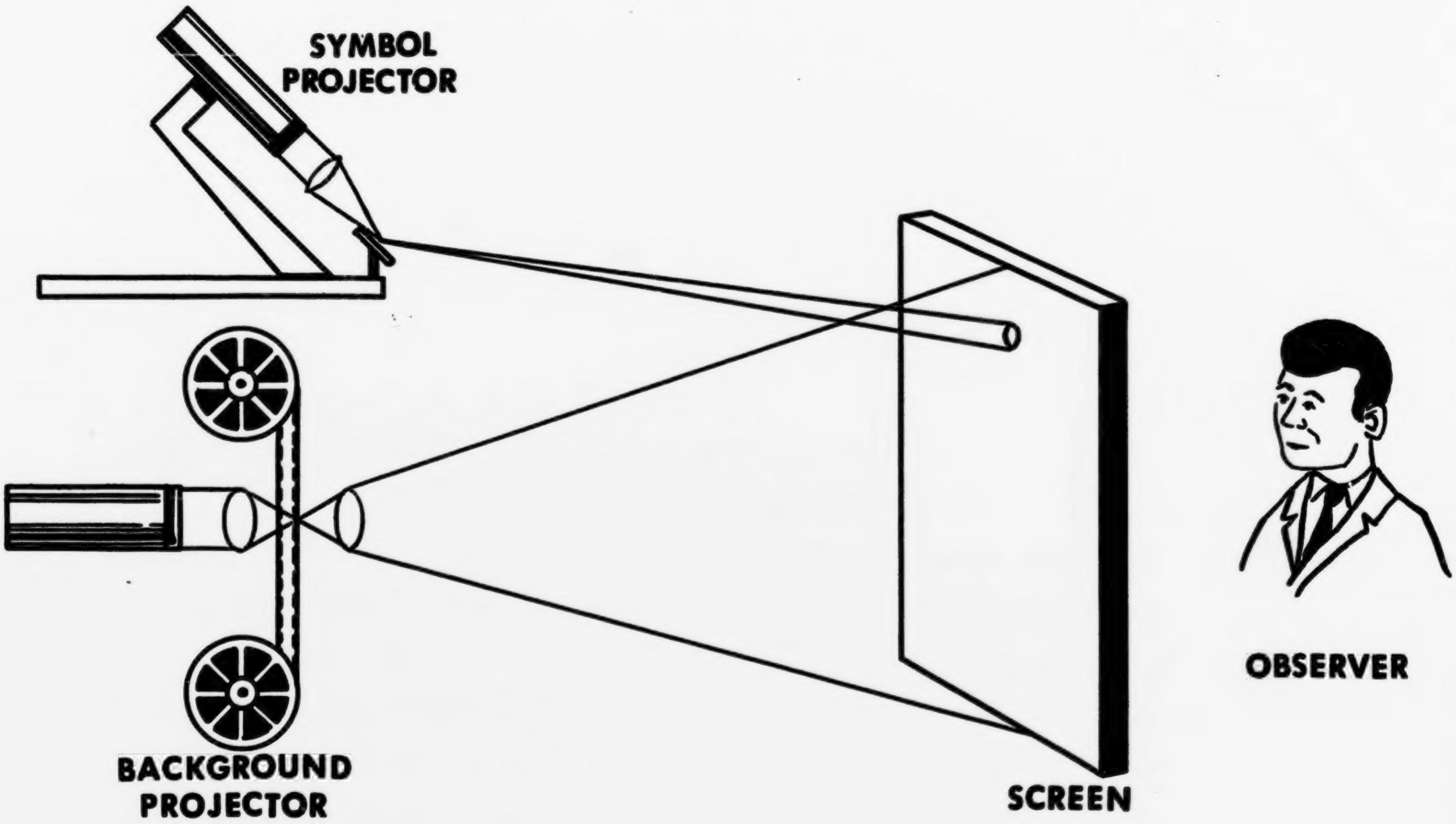

Fig. 3.5. Symbol Enriched Display

Film displays have been described as being basically displays of prerecorded information; this is the manner in which most film displays are utilized. There are two developments, however, which bring the film display closer to real-time conditions. (Real-time operation of any component is generally interpreted as meaning a reaction time that is short compared to the requirements of the system of which it is a part.) One development is the use of developing techniques that can process film in 10 to 15 seconds. This provides the opportunity to photograph new information and update a display within this time period when the necessary film-handling equipment is available. To date, this technique has been used primarily to obtain overlay information such as pointers or special symbols by photographing the screen of a cathode-ray tube, developing the film, and projecting the image against an existing background.

The other development is with a film or slide utilizing a photochromic compound which consists of a molecular dispersion of reversible light-sensitive dyes. The individual molecules are switched from a transparent to an opaque state by light of the proper spectral distribution. Figure 3.6 illustrates the switching property of this material. Switching to the transparent state can be accomplished by either heat or illumination of the proper spectral distribution. Because of the thermal effect, there is a temperature-dependent decay of the opaque material to the transparent state. Decay time will vary, from a few seconds to an hour, depending upon the type of photochromic material. This property, if properly controlled, can be useful in indicating line direction by generating the line at a rate that allows the originating end to decay to a lighter shade than the terminal end. Photochromic material also possesses excellent resolution qualities (Haley, 1963) with an indicated resolution greater than 1,000 lines per millimeter (ordinary film is around 60 lines per millimeter), and although the molecules switch in a binary fashion, the material exhibits excellent gray-scale capabilities.

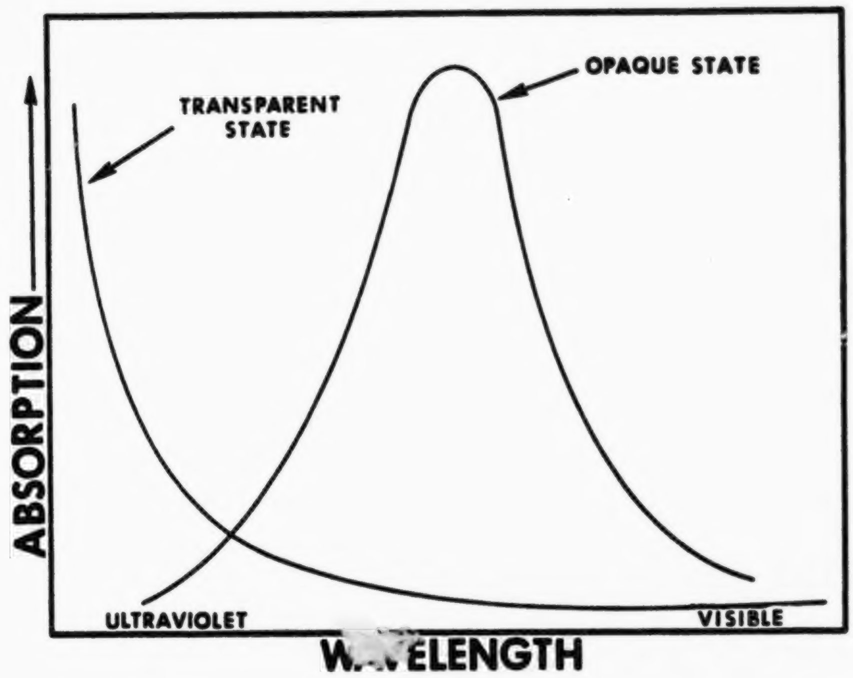

Fig. 3.6. Absorption Characteristics of Photochromic Dyes (Stambler, 1963, p. 94)

Large Screen Displays. A display method that is currently best handled by film techniques is large screen displays for group presentation. Rear projection displays as large as 10 feet by 10 feet have been developed for military applications where use has included the rapid updating techniques described above. Several large systems have been described (Stambler, 1963) which generally contain the system elements illustrated in Figure 3.7 although the particular components and techniques differ between individual systems.

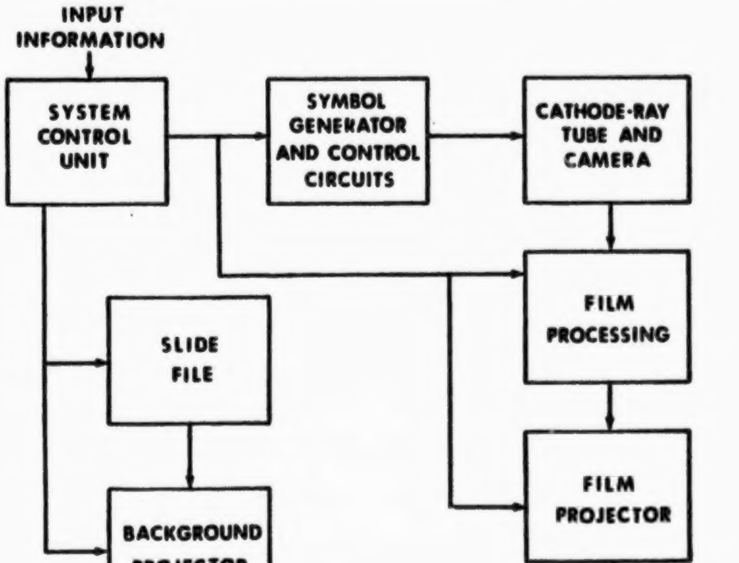
INPUT INFORMATION
SYSTEM CONTROL UNIT
SYMBOL GENERATOR AND CONTROL CIRCUITS
CATHODE-RAY TUBE AND CAMERA
FILM PROCESSING
SLIDE FILE
FILM PROJECTOR
BACKGROUND PROJECTOR
LARGE SCREEN DISPLAY

Fig. 3.7. Large Screen Display Elements

Cathode-Ray Tube Displays

The display device most adaptable to various user requirements and changing display material is the cathode-ray tube. This device, using projection tube techniques, can present large screen displays, or, at the other extreme, can be miniaturized to hand-held individual displays. Light intensity can be made high enough to allow viewing in ordinary light conditions, and the display response times to new information is much faster than a human user can absorb the information. The cathode-ray tube also has the ability to provide user adjustment of brightness level which can be an important factor in changing environmental conditions.

There are many types of cathode-ray tubes with different characteristics depending upon the function to be performed. Those most likely to be encountered in the educational field include the standard single-gun television tube, color tubes, character generators, storage tubes, projection tubes, and perhaps some other special purpose types such as multigun tubes and flying spot scanners. The conventional television picture tube or kinescope is generally well understood, at least with regard to its capability, from its use in home television sets. In home application in the U. S., these tubes operate with a resolution between 25 and 50 TV lines per inch, brightness between 70 and 100 foot-lamberts, large area contrast of around 30, and an aspect ratio (vertical to horizontal dimensions) of 3:4. Industrial or closed circuit television applications may have specifications differing from these because of particular requirements or for economic reasons, but in general the characteristics are similar to those of the home picture tube.

Color Tubes. Additional information is obtained from the pictorial display when color is added. There are numerous approaches to color-tube design although the shadow mask is the most common tube at present. This tube has a multidot tricolor phosphor screen in front of an aperture mask through which electron beams from three separate guns pass to excite the three separate spots on the screen (See Figure 3.8). Each gun is associated with a particular spot color (red, blue or green) and modulated in a manner that will result in the proper combination of the three colors on the screen.

Because of the beam-interrupting action of the mask as the beams sweep out the picture, the light output as a function of single room current is only approximately 20% of that obtainable with monochrome tubes without a mask. The brightness and contrast available with these tubes is only half that which is possible with present day monochrome tubes. The resolution which is primarily a function of spot diameter at the screen with both color and monochrome tubes is between 25 and 50 TV lines per inch.

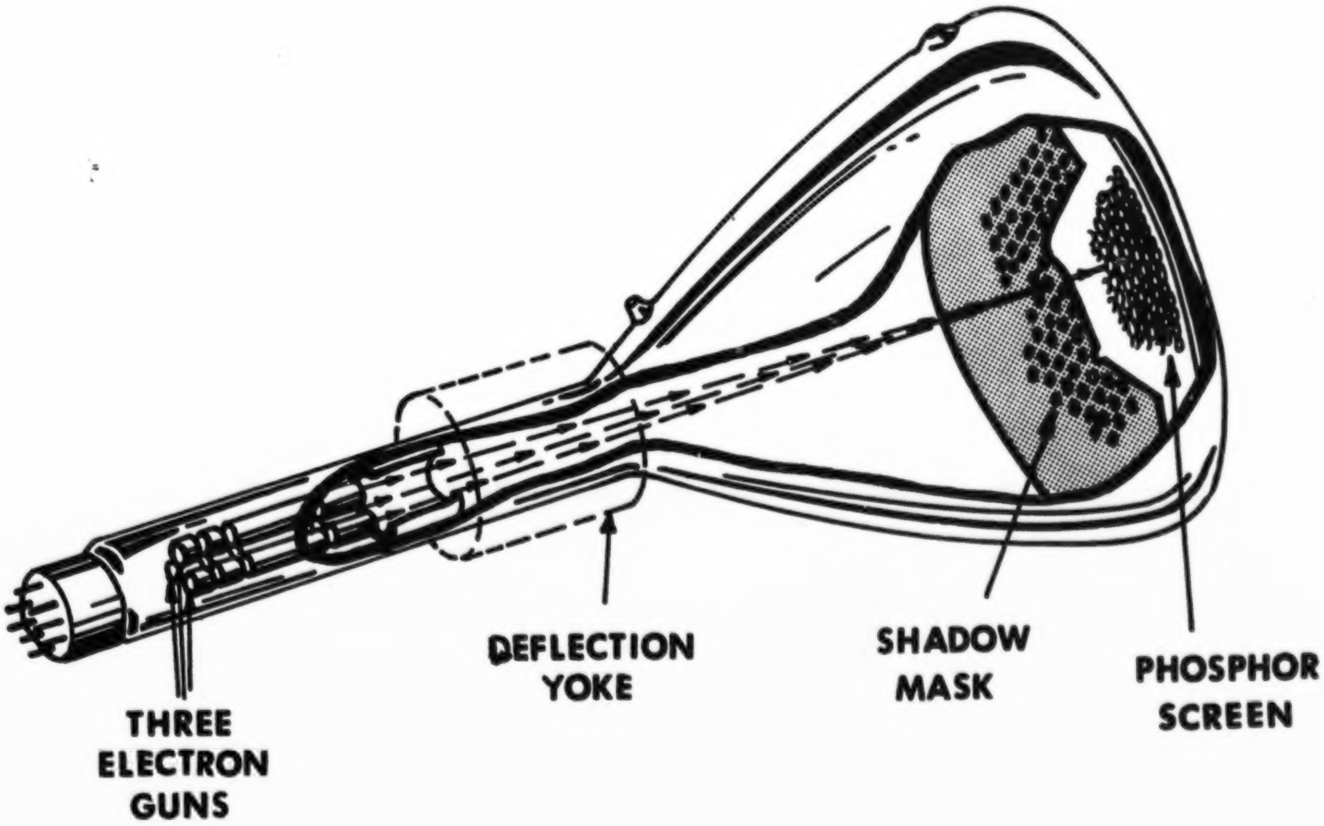

Fig. 3.8. Shadow Mask Color Tube
(Zworykin & Morgan, 1954, p. 793)

Multigun Tubes. Where several traces must be generated at the same time, multigun tubes may be used. This may be necessary if it is not feasible to switch one beam back and forth between different signals in order to generate different traces or when the amount of flicker-free line desired on a tube exceeds that possible with only one gun. To prevent the sensation of flicker, each portion of a trace or display must be regenerated about thirty times a second, and if this is not possible with a single gun, several may be used to increase the amount of flicker-free display. Tubes with as many as ten guns have been made for special applications although the two-gun tube used in many industrial oscilloscopes is probably the most common multigun tube available (excepting, of course, color tubes).

Character Generators. Symbols or characters may be generated for cathode-ray tube (CRT) display by various means. One technique is to modulate the beam in such a manner that the desired symbol is traced on the screen at the desired location. This approach generally makes use of external electronic circuitry that provides the proper modulating signals for a specified set of characters. Another technique is to use special tubes containing a matrix of characters cut in a metal disc through which the electron beam is directed in order to display a particular character. The beam is directed to a given character of the matrix and after the beam is shaped by the matrix character it is deflected by additional signals to a specified position on the display screen. Another technique of character generation is to use the standard TV raster and to modulate the beam appropriately by such means as computer control of auxiliary scanning of symbol sets on film or other media to obtain the modulation. The technique best suited to a given application will depend on factors such as number and mixing of symbols. The special symbol-creating tubes are of course restricted to the character set contained within the tube. However, this technique is perhaps as economical as any, and the tubes are easily capable of generating 20,000 symbols per second.

Shallow-Depth Display Tubes. An innovative design of the direct view display tube is illustrated in Figure 3.9. This tube made by Kaiser Aircraft and Electronics has the advantage of a large tube face and very little depth. Also, by using transparent phosphores and deflecting plates, a display that a user can see through is possible. The beam of this tube enters one corner, and the vertical and horizontal deflection is accomplished by a series of conducting plates which bend the beam at the appropriate locations to focus it on a given sector of the display surface. This tube is still a rather special purpose device, but one which may find increasing applications in the future.

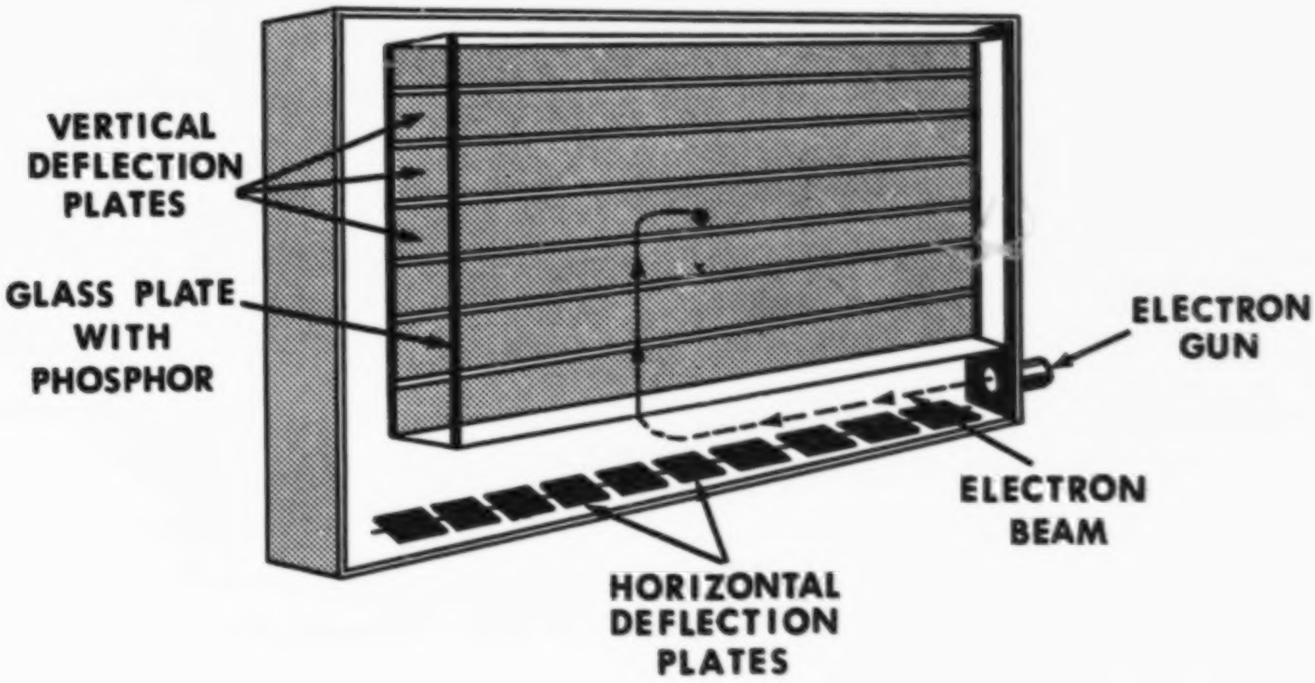
VERTICAL DEFLECTION PLATES
GLASS PLATE WITH PHOSPHOR
ELECTRON GUN
ELECTRON BEAM
HORIZONTAL DEFLECTION PLATES

Fig. 3.9. Shallow Depth Display Tube
(Howard, 1963, p. 91)

Projection Tubes. In addition to the direct view display tubes, which are not normally available in diameters larger than 27 inches, are the projection tubes. These tubes are capable of high values of light output and can provide around 7 foot-lamberts on a 20 by 15 foot screen with the use of a good projection system. This light level compares with standards set by the Society of Motion Picture Engineers for first class pictures. In order to provide this level of illumination, the highlight brightness at the face of the tube is of the order of 30,000 foot-lamberts. The brightness is obtained by using very high accelerating voltages (80 kilovolts in some tubes) which create operational problems of x-ray and power-supply shielding. Also, these tubes must be cooled during operation and have relatively short life compared to the direct view tubes. However, where large screen displays with high information rates (rapid and unpredictable changes of display) are needed, the projection tube is one of the best developed techniques.

Storage Properties. Displays incorporating storage properties are desirable because many display situations do not require continuously changing scenes and in fact demand static displays for some period of time. The necessity of continuously supplying signal information for a non-changing display can present a serious demand to signal sources such as computers, and therefore, it is desirable to have a display capable of holding or storing information until a change is implemented. Cathode-ray tubes that perform this function have been built in sizes up to 21 inches in diameter although the large tube sizes are expensive and difficult to build. The principle of operation is illustrated in Figure 3.10. The storage assembly usually consists of a dielectric material which has a uniform negative charge when the tube is in the blank condition. A writing beam bombarding this dielectric causes secondary electrons to be emitted, resulting in some degree of positive charge at those points which the beam bombards. To display the written traces, a flood gun in conjunction with collimating lenses continuously sprays a shower of electrons toward the viewing screen. The number of electrons that pass through the storage assembly and illuminate the screen is a function of the charge at any point, and hence, presents a copy of the image on the dielectric storage assembly. The negative areas repel the electrons back to a collection electrode; while the more positive the area, the more electrons it passes to illuminate the screen.

Storage tubes, in addition to holding an image or display for presentation, have the added advantage that the continuous stream of electrons to all points of the screen result in more light output than is possible when the display is generated by scanning. A scanning beam in a standard television receiver activates each point only thirty times a second and there is appreciable light decay between scans. With the storage tube, light outputs between 10,000 and 15,000 foot-lamberts can be obtained. The resolution, on the other hand, is not generally as good as with non-storage type tubes due to the defocusing action of the storage assembly. Also, many of these tubes have an erase time of the order of a half second which results in a noticeable blank time or interrupt interval between displays.

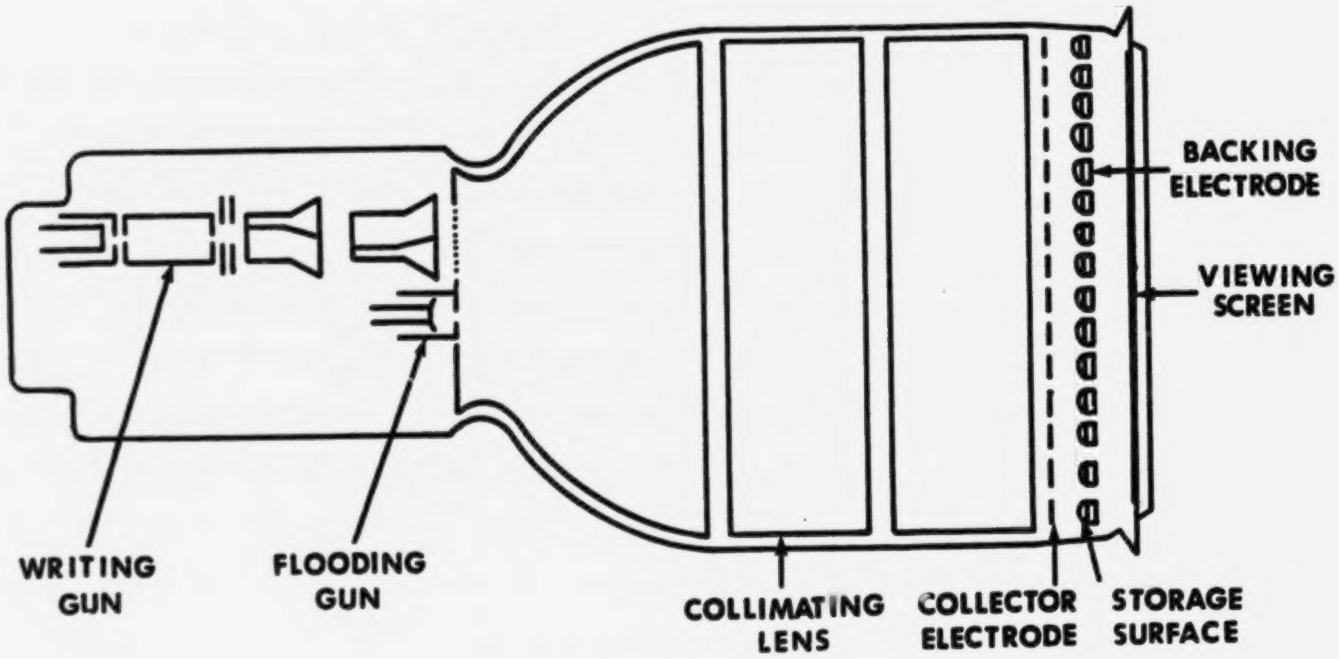
BACKING ELECTRODE
VIEWING SCREEN
WRITING GUN
FLOODING GUN
COLLIMATING LENS
COLLECTOR ELECTRODE
STORAGE SURFACE

Fig. 3.10. Cathode-Ray Storage Tube
(Howard, 1963, p. 99)

Static and Dynamic Display. A tube incorporating both static and dynamic display makes use of different beam energies on a dual-effects target to accomplish the simultaneous displays. This target dielectric is charged by the secondary emission phenomena described earlier, but can also be erased selectively by a high energy bombardment which overwhelms the secondary emission effect. At an intermediate beam energy, the writing and erasing effects cancel to result in the display of non-stored or dynamic information.

Storage-Camera Tubes. Although not a display tube, another storage device that directly relates to display devices is the storage-camera tube. This device has the characteristic of holding an image on its light-sensitive screen which can be continuously scanned by the reading beam. The reading beam is modulated by the stored image and then used to generate a signal that can be displayed at as many viewing stations as desired. The camera must obviously operate as a still picture shutter camera, but it has an additional feature in that multiple exposures can be made to give the effect of "strobbing" or an overlay of stopped-action pictures. Erasure with this type device is done optically and again takes in the order of one-half second.

Scan-Conversion Tube. One other type of storage device which again is not a display device in itself is the scan-conversion tube. These devices, which are often called electrical-read, electrical-write storage tubes, can be presented an electrical signal corresponding to a given display for one complete raster scan and then have a corresponding signal continuously read out to one or more display units. These devices operate on a principle similar to that of the direct-view storage tubes in that a dielectric screen is charged by a writing beam, but instead of having a flood gun shower electrons past the screen, a reading beam scans the surface and is modulated by the variations in charge which it encounters. This modulated signal is then amplified and becomes the input signal for standard display units. The resolution and storage capability of this tube is quite good, with up to 2,000 lines per diameter being possible with continuously read storage times of many hours.

Three-Dimensional Displays. In any discussion of visual display techniques, consideration is usually given to the possibility of generating three-dimensional displays. Several approaches have been made in this direction, utilizing stereoscopic techniques or actual three-dimensional displays. Stereoscopic techniques generally require special glasses to observe the display and are therefore somewhat objectional. The actual three-dimensional displays include multiple layer or stacked devices to obtain a third dimension. Hughes Aircraft has built a "whirling dervish"

(Howard, 1963) device which is a CRT with a phospher screen mounted on an internal disk that is spun at 1800 rpm. The disk, synchronized with the writing beam, can generate a three-dimensional display, but it is obviously difficult to build and operate.

Response-Detection Device. The cathode-ray tube may be used as an input or response-detection device as well as an output display or stimulus device when associated with a light pen. Figure 3.11 illustrates the technique. A light-sensitive device, usually in the form of a pen, is held near the screen of the CRT and when the light-generating electron beam passes the pen, a detectable electrical pulse is emitted by the pen which then can be correlated with the beam position. This relationship establishes the position of the pen which can be interpreted in accordance with the dictates of a particular program. Techniques of this sort have been described in papers (Stotz, 1963; Sutherland, 1963) related to the computer-aided design project at MIT.

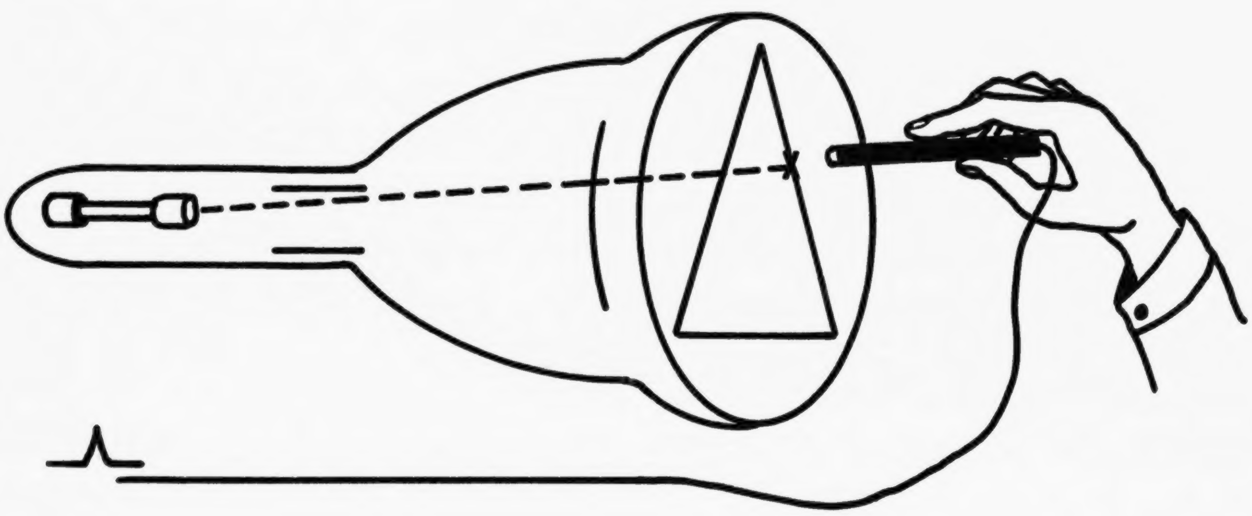

Fig. 3.11. Light-Pen Response Technique

The discussion of a light-pen application to displays implies a program logic and sophistication that can be implemented only through computer devices. This report has not concerned itself with the techniques behind the interface, but it is probably appropriate to mention here that CRT displays making use of light-pen techniques and under control of a computer allow the generation of displays in response to a student's action that may never have been created before. Also, it may be possible by utilizing current knowledge relating to pattern recognition to analyze such displays from a subject-matter viewpoint and provide a very personalized and innovational instruction sequence.

Electroluminescent Displays

There are, in general, three methods of stimulating phosphors to obtain light output: these are photoluminescence, cathodeluminescence and electroluminescnece. In photoluminescence, ultraviolet photons are used to stimulate the phospher, and in cathodeluminescence a high energy beam of electrons (as used in cathode-ray tubes) is used to cause light emission. Electroluminescence is the direct conversion of electrical energy into light within the phosphor. The phosphor is contained in the dielectric of a capacitor which has at least one translucent plate through which the light can be emitted. Figure 3.12 illustrates the basic components of this type of light source.

The electroluminescent display is particularly advantageous where an area source of light is desired or where a flat or basically two-dimensional source is required. The individual elements (capacitors) can be constructed either on a rigid base such as glass or metal, or on a flexible material like plastic. When conditions require, the elements may be embedded in very durable materials that can withstand environmental conditions of mechanical shock and wear that would have catastrophic effects on evacuated bulb devices like the cathode-ray tube. These displays have a wide viewing angle without parallex; light output is in the range of 10 to 20 foot-lamberts; and the power requirements are in the milliwatt range.

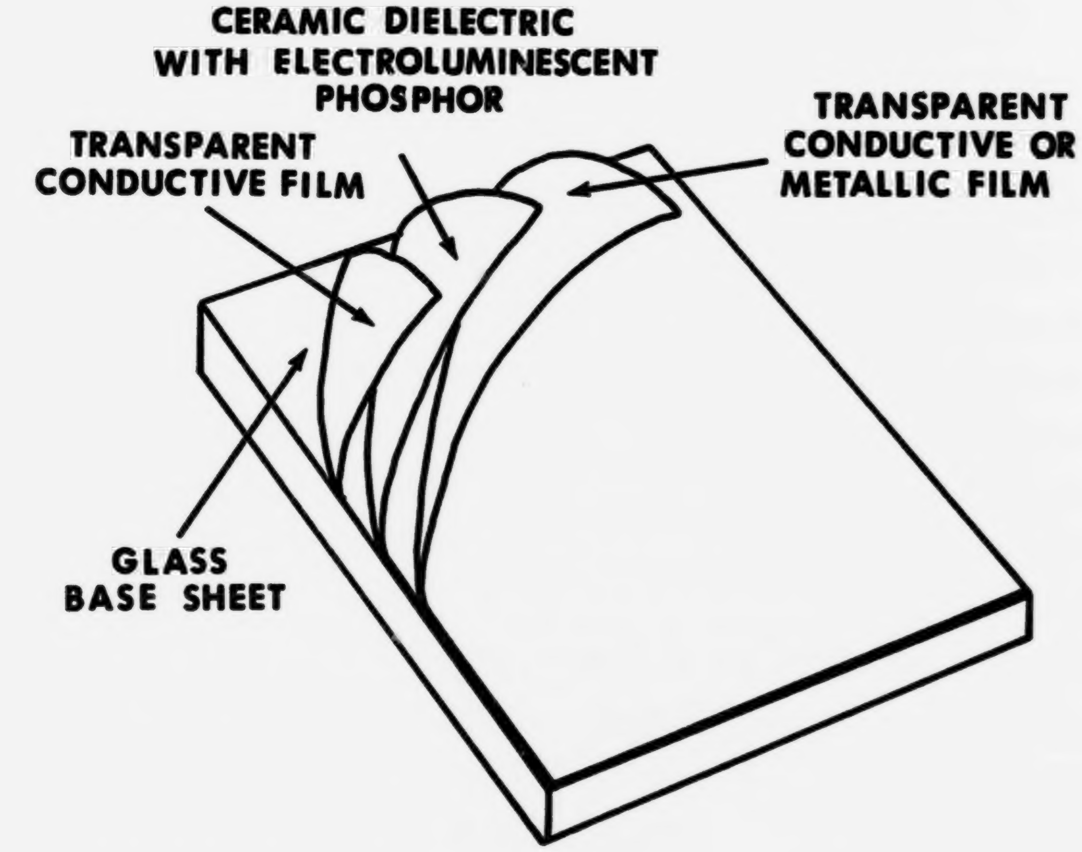
CERAMIC DIELECTRIC WITH ELECTROLUMINESCENT PHOSPHOR
TRANSPARENT CONDUCTIVE FILM
TRANSPARENT CONDUCTIVE OR METALLIC FILM
GLASS BASE SHEET

Fig. 3.12. Electroluminescent Lamp
(Sylvania Inc.)

Light outputs in the 80 and 100 foot-lambert range can be obtained by increasing the voltage and frequency. Figure 3.13 illustrates typical curves for brightness as a function of frequency and voltage.

Electroluminescent phosphors are obtainable in four different colors. These are green, blue, yellow, and white with the relative brightness of the latter three being around 60%, 50%, and 40% respectively that of the green. Color is also dependent upon the frequency of the electrical excitation: the green phosphor can be caused to shift to a bright blue by increasing the frequency from 400 cycles to about 20 kilocycles. Red is also available as another color by using a fluorescent dye; however, the light output is lower than that of the other colors.

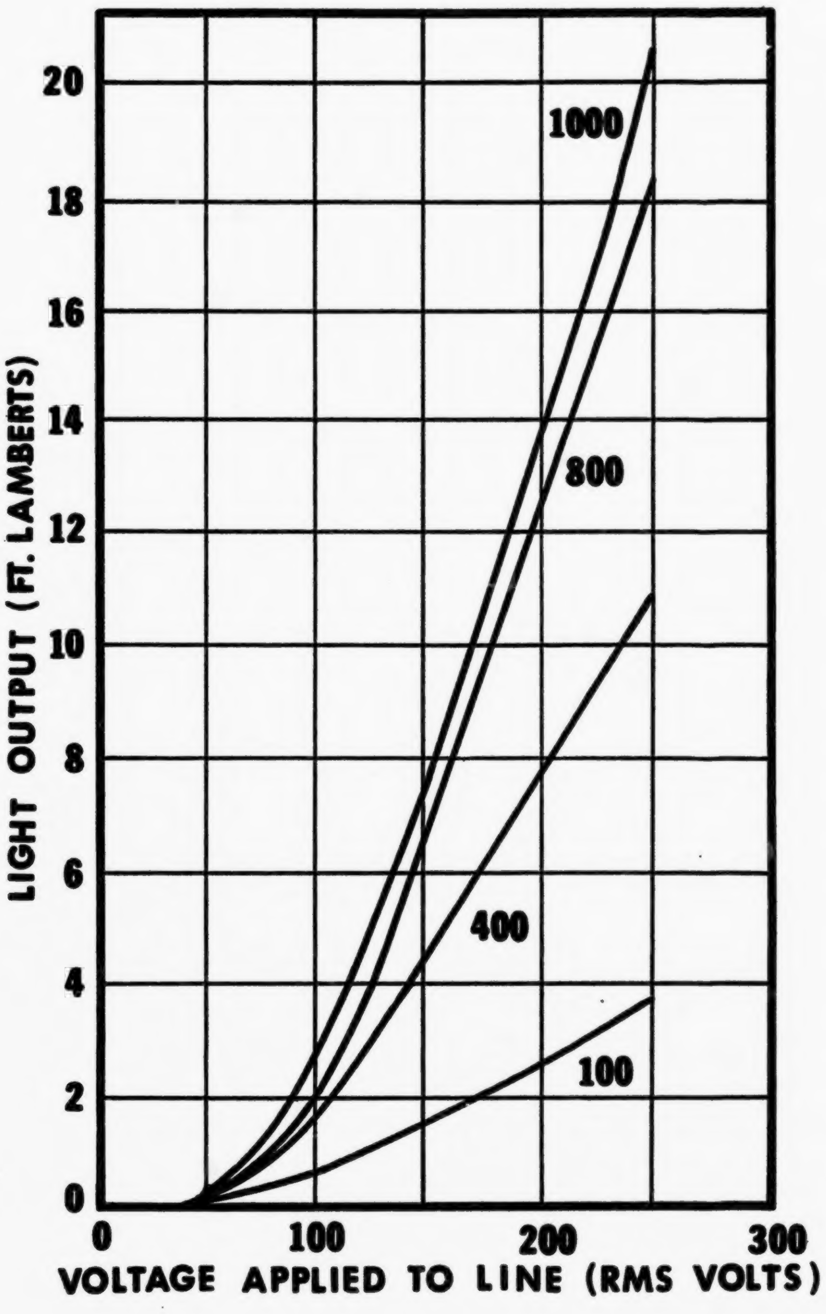

Fig. 3.13. Variation of Panelescent Lamp Brightness (Sylvania, Inc.)

Display Retention. The problem of display retention or storage which must be provided for most display techniques other than film can be accomplished in electroluminescent devices by utilizing a photocell feedback arrangement. Figure 3.14 illustrates one technique used to accomplish this storage function for individual segments of a display. When a given segment is activated by closing the set switch, light from the electroluminescent element causes the internal resistence of the photocell to decrease so that the electrical path from the power source to the electroluminescent lamps will be maintained even after the set switch is opened.

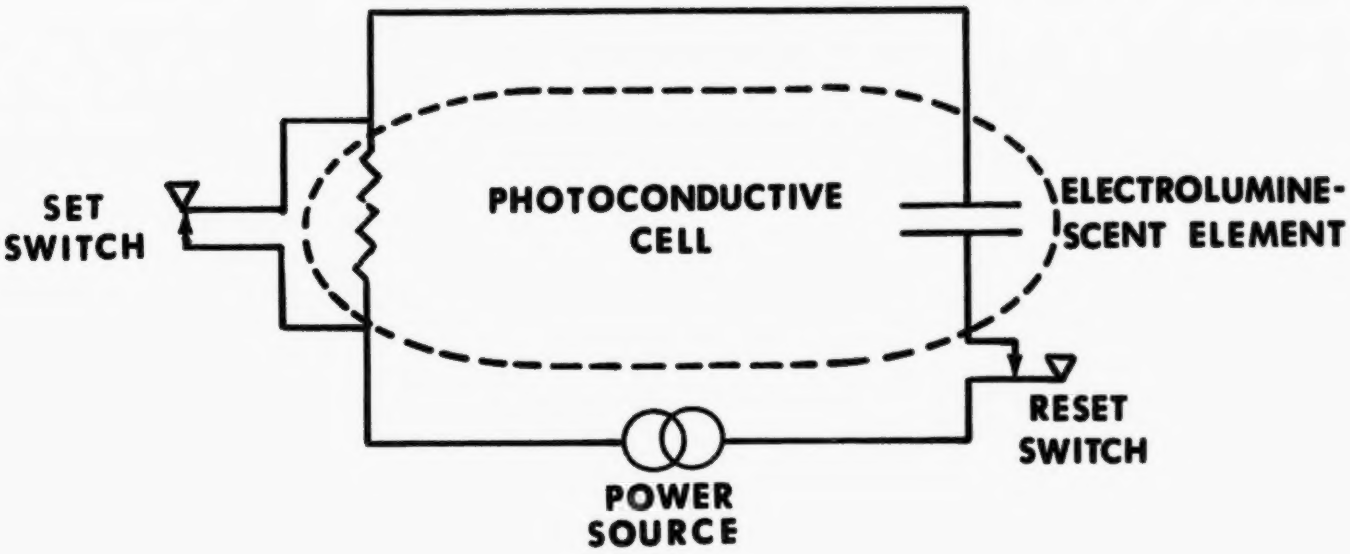

Fig. 3.14. Photocell Storage Technique

To extinguish the element the power source must be interrupted through a reset switch. These photoconductive elements can be prepared in a thin layer form which allows a high density of elements, and the storage can then be made as a part of the display unit.

Decoder. Another use of the photoconductive element is as a decoding device between the information source and the display. Figure 3.15 illustrates a technique of converting decimal information (one of ten) into a graphical display symbol. Element A shows an electroluminescent lamp with the top conductive layer patterned into ten strips (0-9) resulting in a ten-element lamp. A non-strip photoconductive device is shown at element C. Each photoconductive strip is in a series with its corresponding segment in the numeric panel. A mask or overlay is inserted between the electroluminescent and photoconductive layers. When electroluminescent strip number seven is on, the light from it strikes only the a, f, and n strips of the photoconductive material. They will become conductive and the a, f, and n segments of the display will light.

Arbitrary Pattern. Displays of rather arbitrary pattern can be created through the technique of crossed grid of conductive strips.

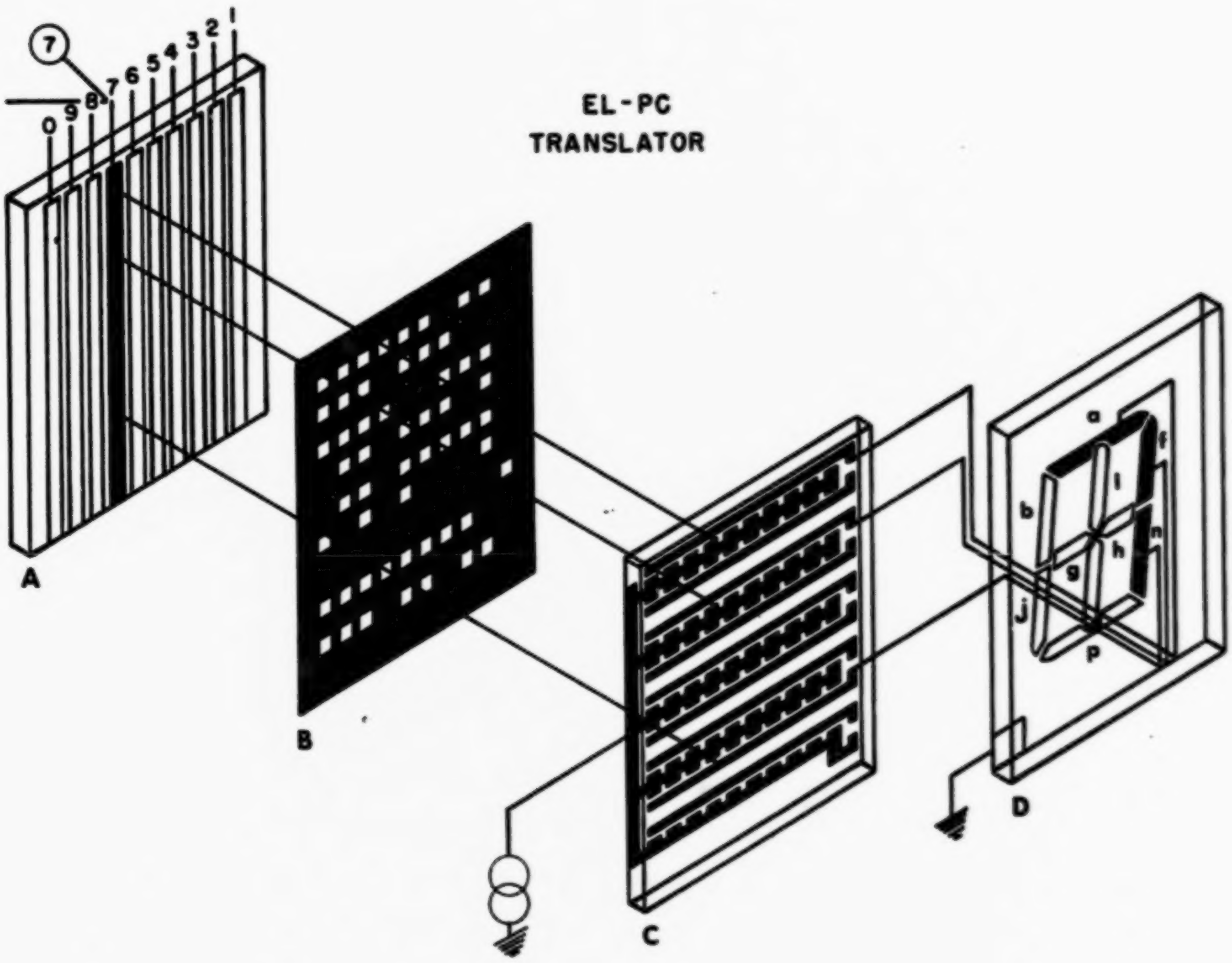

Fig. 3.15. Photoconductive Decoding Technique
(Sylvania, Inc.)

Figure 3.16 illustrates a method of forming a coordinate system of separated "x" and "y" strips. Remembering that light is emitted only where there is capacitive coupling, the application of a potential on one "x" line and one "y" line will result in a bright spot of light where the lines cross. This potential, however, causes one-half the voltage to be applied to the entire row and column which results in a faded "cross" effect. That is, each line will emit some light along its entire length although much dimmer than at the point of instruction. In some applications this "cross" effect may be useful, but if it is objectional, it can be suppressed by the incorporation of a nonlinear restrictive layer. The response time, which is limited by the capacitance of the elements, is about ten micro-seconds.

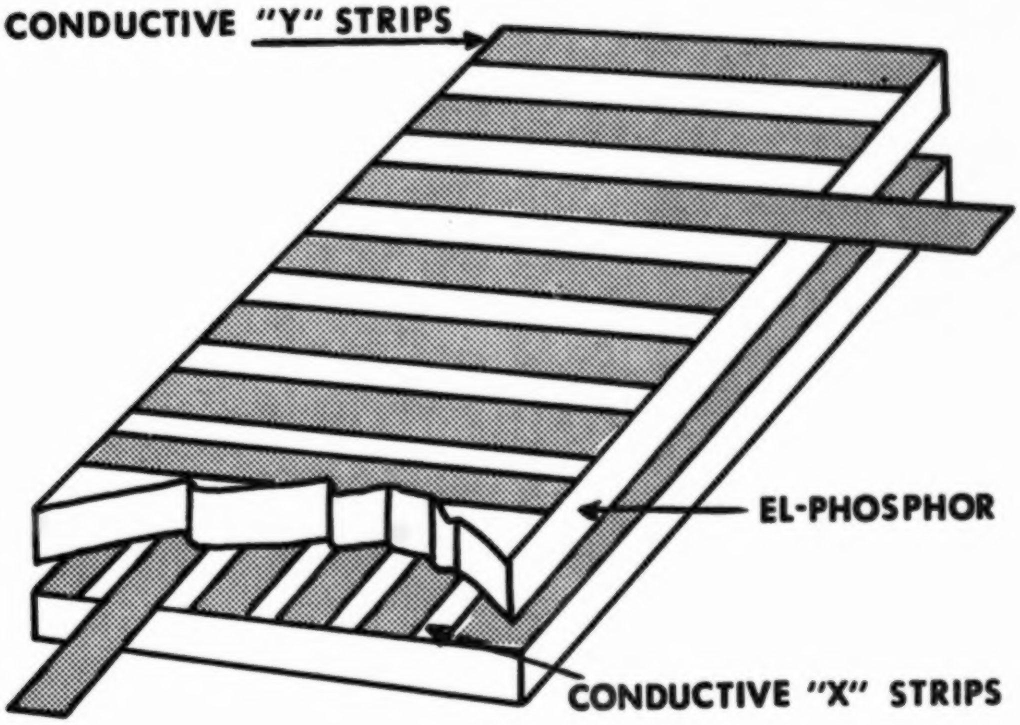

Fig. 3.16. Crossed Grid Display Technique
(Sylvania, Inc.)

Developments in Electroluminescent Displays. Continuing development work with electroluminescent displays has included concepts of large screen (10 feet by 10 feet) displays, improved information storage methods, gray scales, resolution, and techniques of control. Developments with large screen techniques containing both gray-scale possibilities and self-contained storage in the display elements have been reported (Sack, Wolfe, & Asars, 1962) as well as new techniques of spot control utilizing piezoelectric materials rather than the technique of a crossed grid (Yando, 1962). The new spot control approach holds promise of simplified equipment and hence potentially more reliable displays. The continuation of work of this nature as well as continuing work on electroluminescent materials themselves will lead to interesting large area displays in the future.

Auditory Communication

Auditory stimulus presentation and response detection is a second major human-sensory mode and means of communication. If one is accustomed to learn by auditory presentation (as is true for young children), more rapid learning may result through its use than through other modalities (Underwood, 1949). Sounds are a significant part of the normal child's everyday experience and soon come to have certain meanings. These sounds need not be verbal languages but less complex sounds in the individual's environment. Simple sounds like car horns, fire whistles, door bells all have associated meaning for a particular person. More complex sounds such as the patterns generated during verbal communication are used to convey a variety of meanings depending upon their relationships within a sequence of sound patterns. The use of verbal sound patterns both for stimulus display and for a response mode is a "natural" method of communication in that it avoids the necessity of teaching the student to operate a special device (such as a pencil) in order to communicate.

Auditory stimuli when used in the educational area must be adjustable to both learner characteristics and subject-matter requirements. In order to adapt to different display request rates and to avoid excessive "wait" times by the learner, some degree of random access to the display of verbal material is required. When the recognition of spoken responses is involved, the equipment must be able to detect speech sounds at times initiated by the student. These requirements place restrictions on vocabulary size when access and recognition times in the order of a second are desired and tend to limit the amount of material that can be communicated in this manner.

In general, auditory displays are advantageous, particularly with young children, because competency in speaking and listening are developed before precise visual discrimination required for reading, and because of the independence of the individual's orientation with respect to the display source. Also, when visual communications are heavily engaged or limited because of environmental conditions, the auditory channel is generally the next best method of information transfer.

General Considerations

The field of auditory perception with respect to the hearer is virtually independent of his orientation with a uniform display in the low frequency range (below 5000 cycles per second). This feature (i.e., that sound can reach the hearer regardless of his position in a room) is important in tasks requiring movement on the part of the hearer or in the performance of tasks physically dissociated with the signal source.

The binaural nature of the auditory channel provides directional properties and characteristics which allow the simulation of motion. This phenomenon is easily controlled when headsets are used as the sound source. If the situation requires physical movement on the part of the participants, headsets might be undesirable and binaural effects would have to be obtained by proper room design and location of speakers.

Other parameters of auditory communication are loudness, duration, and pitch. These parameters are easily varied with present-day equipment and can be used to either adapt to a particular environment such as a noisy room or to provide additional meaning for a given display.

Stereotyped-Sound Displays

Communication by sound can range from simple tones and sound patterns to stereotyped messages and complex speech patterns. Table 3.1 lists common types of simple devices (horns, bells, etc.) that are used to present "on-off" information or information about the existence of a particular condition. Although these devices are primarily "on-off" devices, their information-carrying capacity can be extended by coding procedures such as varying the duration of signal, interruption rate, and sequential pattern. Chimes, for example, use sequential coding as the principal technique of encoding information. It is possible (Pollack, 1952; Pollack, 1953) to transfer between 6 and 7 bits of information per display for such elementary devices when properly encoded.

The oscillator is perhaps the most versatile of all the simple devices in that it is easy to vary such parameters as frequency, intensity,

Table 3.1

Device	Frequency range	Attention getting ability	Noise penetrating ability	Possible stages
Horns	Low to High	Good	Good	On-Off
Whistles	Low to High	Good if Intermittent	Good	On-Off
Bells	Medium to High	Good	Good with low Frequency Noise	On-Off
Buzzers	Low to Medium	Good	Fair	On-Off
Chimes	Low to Medium	Fair	Fair	On-Off
Oscillators	Low to High	Good if Intermittent	Good with Proper Frequency Choice	Range of Frequencies

Modified from: Morgan, C. T., Chapanis, A., Cook, J. S., III, & Lund, M.W. Human Engineering Guide to Equipment Design. McGraw-Hill Book Company, Inc., 1963.

and sequential pattern in order to obtain a multidimensional display with one device. This unit, as the others in Table 3.1, is probably most useful as a feedback and cueing display rather than an element of a subject-matter display.

Auditory displays with more information content than that described above encompass verbal messages of varying length. The technique most commonly employed in the reproduction of stored displays is the use of magnetic tape devices or of pressed discs (records) depending upon the application and quantity involved. Magnetic tape equipment used primarily as a voice recording and reproducing technique has the advantage of flexibility; it is easily altered with erase and rewrite techniques and is easily copied and edited. The advantages of disc recordings include less susceptibility to inadvertent damage and the loss of information. Neither type of storage is satisfactory when fast access (order of one second) to randomly stored displays is desired. Special equipment can be built for either locating a pick-up over a desired section of a disc or for moving a tape to a desired location; however, the addition of equipment of this nature substantially increases the cost of the basic equipment.

A recent technique used for recording relatively short messages (less than five minutes in length) is to make use of magnetic cards. Cards of a size and shape that will allow mechanical manipulation and selection are provided with magnetic coatings that can be scanned by reading and writing devices to either reproduce previously recorded messages or to record new messages on the card. One example of such a technique is used in the Edison Responsive Environment equipment manufactured by Responsive Environments Corporation of New York. This equipment has as one of its features a verbal display which can be associated with both a visual display and a student response through a keyboard device. The technique employed is to use large cards which have one side available as a visual display and the other side coated with a magnetic material for recording the verbal displays. The flexibility of programming and amount of audible display available with this technique is a big step toward fast random access of audible display. Other types of magnetic card handling equipment have appeared in the digital computer field with National Cash Register's CRAM System and the RCA RACE System where random access to billions of computer characters is available with access times in the order of 200 to 400 milliseconds.

Generated Sound Displays

Generated auditory displays for the purposes of this report will be interpreted as those compositions created from a set of simpler basic units than the composition itself. The arrangement and sequential timing of these units in relation to each other determine the composition; by varying the program or rules of composition, new displays never presented before can be created. Music can be considered to be in this category when it is created by supplying control signals to an instrument of some kind rather than selecting for display a previously recorded version. Rules of composition that will produce a pleasing (natural sounding) verbal display are not well established, and only approximations to verbal displays, although intelligible, can be made at the present time.

In considering methods of categorizing the various approaches to speech generation, F. S. Cooper (1963) differentiates between what he has termed compiled speech, synthetic speech, and speech produced from hybrid methods or combinations of techniques. Compiled speech is that produced from a random-access memory of pre-recorded words or phrases. The technique is to store recordings of words or phrases with careful attention to the most typical pronunciation and intonation for the type of presentation under consideration. Synthetic speech is the controlled operation of a synthesizer using a phonemic description of the desired composition to determine the appropriate control signals. The technique is to apply a set of rules that specify formant frequencies and the transitions from one set of frequencies to another in order to create a particular sequence of phonemes. The hybrid technique combines storage and synthesis. An example would be the storage of "standardized" sets of control signals that would be used to operate a speech synthesizer. For example, a set of control signals necessary to produce syllable-like sounds may be stored and the operation of the system would be to select the desired elements of the set in some particular sequence.

Compiled Speech. The approach most commonly encountered in practice where generated verbal displays are used are those of the compiled speech category. A system built by the Teleregister Corporation (Van Gelder, 1964) to provide compiled announcements of stock market transactions to subscribers of the system has been reported. This system has a memory of only 62 words or parts of words and compiles announcements from this limited vocabulary by spelling the abbreviations of stock listing. Each word or unit of this system is 350 milliseconds or less in duration and longer words are broken into two separate parts that are joined during the compilation process.

IBM has also reported an Audio Response Unit capable of providing a vocabulary of 128 five hundred millisecond words or part words. The system composes messages at high speed onto a temporary storage unit which then presents the composition at normal speech rates to the output associated with that storage unit. The audio response unit operates in conjunction with a digital computer which determines the message composition by specifying a sequence of words to be read into any particular output storage unit. For example, in a course of college chemistry, a request may be made for the formula of alcohol. The computer upon receiving such a request will then compute and generate the necessary sequence of control signals to call forth from the audio unit the proper sequence of stored sounds that will create the desired formula.

The techniques of sound storage and retrieval (referred to above) become expensive relative to other techniques of storage and retrieval as the vocabularies become large (1000 words or more). A more economical way of storing such sounds would be on magnetic tapes which are capable of being addressed to the location of a particular sound unit. The composition of a sequence of sound units would then have to be collated on a temporary storage unit and played back to the listener after the entire message has been collated. This is necessary since the access to various portions of the main tape storage can be in the order of seconds or even minutes to get to a particular sound unit. This composing time, therefore, eliminates the possibility of fast replies (within a second) or audible presentations immediately following the initiation of some action.

Synthetic Speech. In synthetic generation of auditory composition, the application of a set of rules activates the control signals associated with a synthesizer in order to produce meaningful sounds. Perhaps the type of synthesizer most generally known is the vocoder which has been experimented with since the mid-thirties. The vocoder, operating as a communication device, has both an analyzer and synthesizer of speech sounds. The analyzer converts the speech sounds into control signals (usually digitally encoded signals) which are transmitted to the synthesizer which then reconstructs the speech pattern. For purposes of generating speech sounds that have not been previously uttered, only the synthesizing portion of the vocoder and the rules or formulas for determining the proper sequence of control signals are needed to generate meaningful sounds. Figure 3.17 illustrates the basic items of equipment incorporated in the synthesizer of a common type of vocoder. The buzz generator is used to create the fundamental frequency (usually in the order of several hundred cycles) and its harmonics. The hiss generator creates a broad spectrum of frequencies used in synthesizing unvoiced consonants. The ten bandpass channels determine the amount of energy transmitted through that portion of the frequency spectrum which they control. The outputs of these channels are then combined in a summing amplifier and presented as synthesized speech to an output speaker.

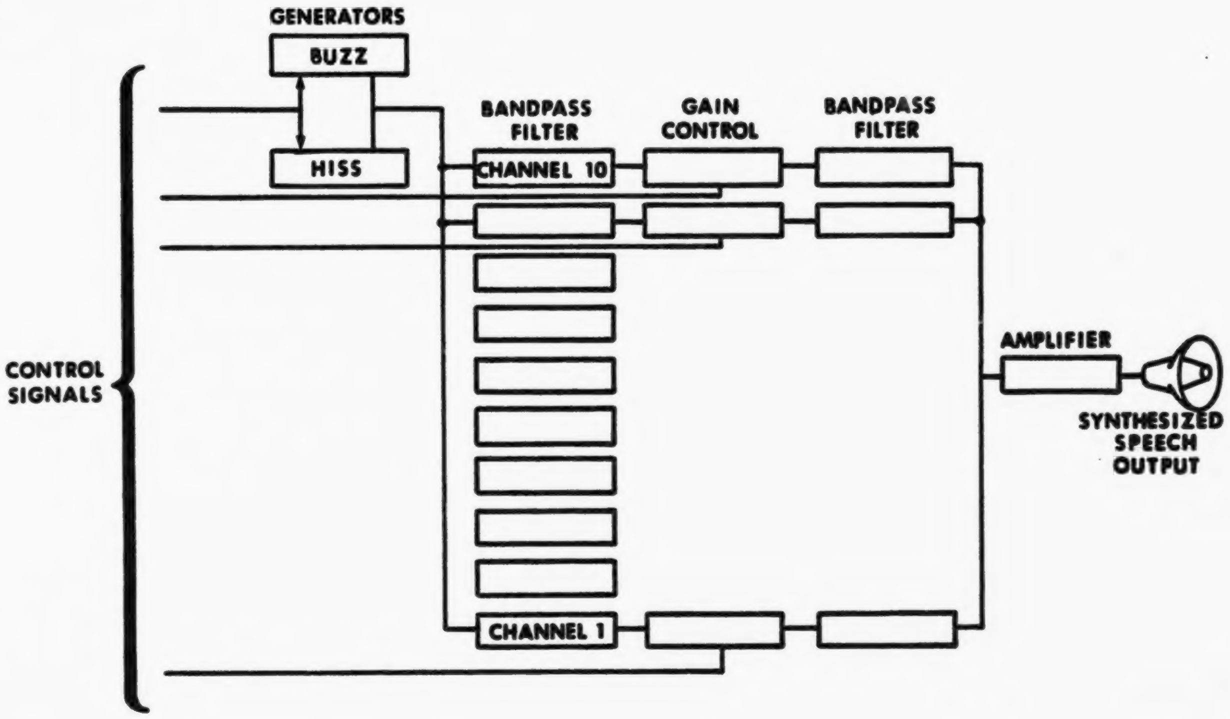
GENERATORS
BUZZ
HISS
BANDPASS FILTER
GAIN CONTROL
BANDPASS FILTER
CHANNEL 10
CHANNEL 1
CONTROL SIGNALS
AMPLIFIER
SYNTHESIZED SPEECH OUTPUT

Fig. 3.17. Fixed Channel Vocoder Synthesizer

Another type of synthesizer used experimentally is illustrated in the schematic diagram of Figure 3.18. This device called a resonant synthesizer adjusts the resonant (natural) frequencies of a set of circuits whose frequencies correspond to the primary resonances of the vocal tract. These circuits are driven by the outputs of buzz and hiss generators. By controlling parameters such as the resonant frequencies of the circuits, amplitude and frequency of buzz generator, and amplitude of hiss generator, intelligent speech sounds can be created. The synthesizer illustrated in Figure 3.18 contains a separate circuit for the fricative sounds in order to improve the naturalness of the speech.

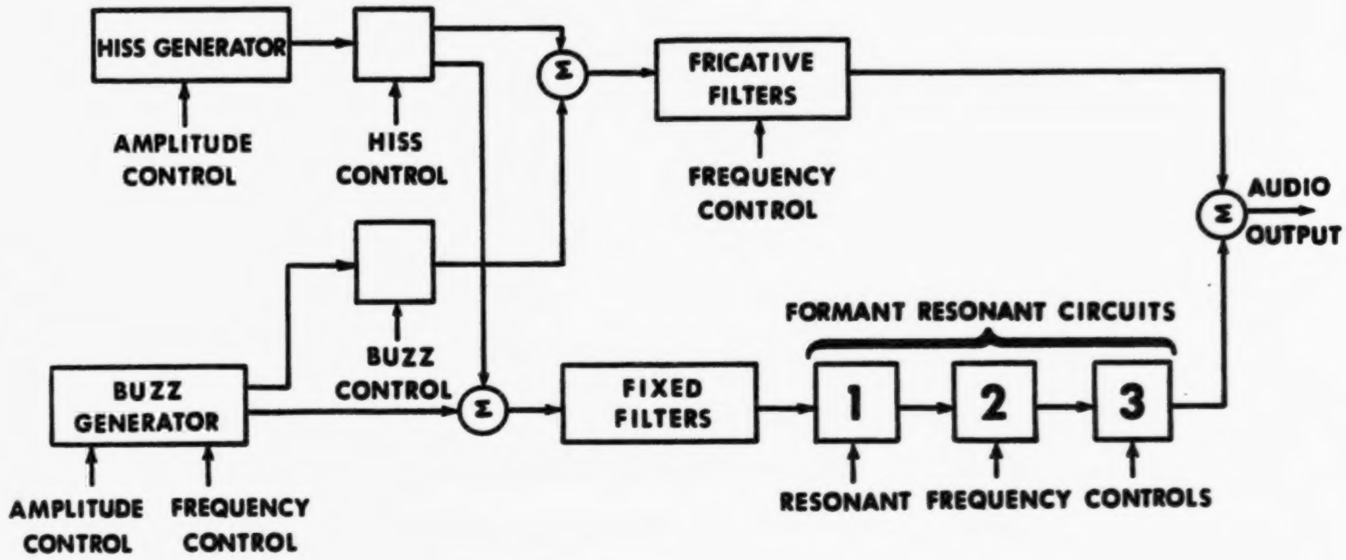
HISS GENERATOR
AMPLITUDE CONTROL
HISS CONTROL
Σ
FRICATIVE FILTERS
FREQUENCY CONTROL
Σ
AUDIO OUTPUT
FORMANT RESONANT CIRCUITS
BUZZ CONTROL
BUZZ GENERATOR
Σ
FIXED FILTERS
1
2
3
AMPLITUDE CONTROL
FREQUENCY CONTROL
RESONANT FREQUENCY CONTROLS

Fig. 3.18. Resonant Type Speech Synthesizer
(Estes et al, 1964)

Digital computers have also been used to synthesize speech patterns on magnetic tapes which can then be used on regular tape recording equipment. This work (Kelly & Gertsman, 1962) indicates the possibility of talking computers when the transducer of the tape recorder is a part of the computer system.

Synthetic generation of speech implies the existence of a description of the speech pattern desired. Much of the work to date in this respect has been to study units of speech or the acoustic cues that listeners use in perceiving speech and from these to specify the characterics of the sound pattern needed to produce meaningful speech. A set of rules of this type have been summarized (Liberman, et al., 1959) which are minimal in the sense that the rules have been kept as simple as possible, consistent with intelligible speech. These rules make use of the phonemic descriptions of speech which specify the requirements of the individual phonemes and which specify the interactions between successive sets of rules. Also, to achieve a degree of naturalness, rules specifying pitch and intensity information can be added to these basic phonemic rules.

Hybrid Techniques. Hybrid techniques of speech generation combine both storage and synthesizing techniques in the generation of speech sounds. The stored units may be recorded sounds such as phonemic or syllabic transcriptions that are combined according to specified rules in the output device; on the other hand, the storage may consist of tables of control signals required to operate a particular synthesizer.

A hybrid system making use of stored syllables has been described (Olson, 1964) that will accept coded input, and with a storage capacity of approximately 1000 syllables, will generate intelligible speech for most practical applications. A syllable as defined for this system is not necessarily the same as that used in a conventional dictionary, but is more specifically a grouping of two or more phonemes considered as a unit. A diagram of the basic elements of this system is shown in Figure 3.19. The decoder and word selector translates the coded specifications of the required speech into a set of machine instructions. These instructions together with the associated time controls and synchronizers cause the proper sequence of syllables to be read out of the main storage unit and assembled on a temporary storage unit from which it is then transmitted to an output unit.

An example of a system incorporating the storage of synthesizer control signals is the resonant synthesizer illustrated in Figure 3.18. In this system nine control signals are used to operate the synthesizer. The amplitude and sequence of these signals for specified segments of speech are stored on some associated medium such as magnetic tape or punched cards. The sequence of speech segments desired, and operations on them such as repeating segments or changing pitch of a group of segments is required as input that will generate intelligent speech.

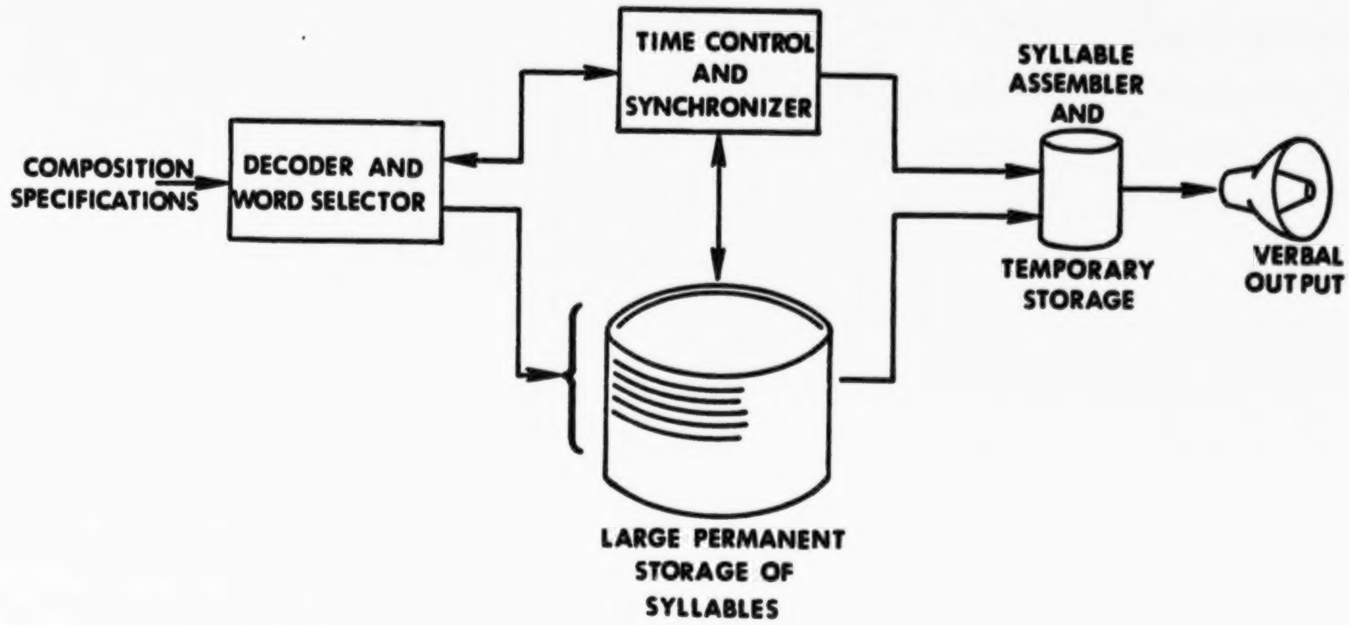
COMPOSITION SPECIFICATIONS
DECODER AND WORD SELECTOR
TIME CONTROL AND SYNCHRONIZER
SYLLABLE ASSEMBLER AND
TEMPORARY STORAGE
VERBAL OUTPUT
LARGE PERMANENT STORAGE OF SYLLABLES

Fig. 3.19. Speech Synthesizer Utilizing Syllable Storage

Comparison of Display Methods

In comparing the different approaches toward the generation of speech, the most obvious distinction is perhaps the trade-off between storage requirements and design sophistication. The generation of speech by compiling words requires a very large storage but fairly simple logic, while speech generated by rules requires only modest storage but more sophisticated logic. Cooper (1963) has estimated that the storage required to accomodate a vocabulary of 20,000 words would be in the order of 400 million bits for compiled speech, 40 thousand bits for synthetic speech, and between one and ten million bits for the different hybrid methods.

The communication bandwidth requirements or bit rate is another factor to be considered in the design of speech generation equipment. If the input bit stream generated the speech, 30,000 to 50,000 bits per second would be required to generate intelligent speech. The vocoder on the other hand produces good quality speech with an input rate of around 2500 bits per second, and the resonant synthesizers operate with around 1200 bits per second which is within normal telephone line capabilities. Olson (1964) has pointed out that a compiling system utilizing syllable storage requires only about 23 bits per second to produce speech at normal rates of talking. This figure is interesting in that it corresponds closely to the rate at which humans have been found to be able to assimilate and process information (Quastler, 1956).

Output quality should also be considered in evaluating different approaches to speech-generating systems. Comparisons between the different techniques of generation are not known to exist and, in part, would probably not be meaningful at the present state of development. A user of equipment of this type will probably want to make intelligibility test of words or sentences in order to be able to predict the results of the use of such a system. Techniques for making such tests are covered by Morgan, Cook, Chapanis & Lund (1963) in their discussion of speech communication.

Speech Recognition

Verbal communication is normally a two-way process with each communicant participating in both speech generation and speech reception. The recognition of speech by equipment appears to be a more difficult task than speech generation, and only a very limited approach toward its realization has been achieved to date.

The recognition of speech is difficult not only because the acoustic cues of verbal communication are not yet completely understood, but also because the receptor must be capable of adjusting to the allowable variations within the presented speech. As a receptor of speech, the interface and its associated equipment must be capable of adapting to different characteristics, such as speaker intonation, variation of loudness, and rapidity of speech encountered in a particular environment. Also, a reasonable degree of background noise must be accomodated in most operating environments, adding to the difficulty of accurate recognition.

In an instructional environment, the equipment must react with some immediacy to the responses of the student. This property places a speed requirement on the equipment and constrains the amount of analysis that can be done on the received speech patterns.

The techniques used in the analysis of speech patterns include an amplitude-frequency-time description of the received speech. This description is basically obtained as with the analyzer portion of a vocoder where bandpass filters segment the input into frequency channels which have separate amplitude analyzing circuits. These channels are them sampled as a function of time to obtain a pattern than can be analyzed. The processing performed on the extracted parameters is generally a function of the particular approach being studied or used. It may vary from a specialized approach operating with speech cues to a more general pattern recognition scheme which attempts to detect the salient and consistent parameters of a repeating pattern.

Several implementations of speech processing systems have recently been described (Sakai & Doshita, 1963). Sakai and Doshita have described a system in which the phoneme is used as the basic recognition unit. This system requires some adjustments for individual voices and may accept all connected speech sounds although the present implementation requires that the words be clearly and somewhat slowly spoken.

Olson (1964) has described a speech analyzer which translates the input into a syllable code by means of the basic information obtained from an amplitude-frequency-time description. The system described has a recognition vocabulary of around fifty words and an accuracy of 98 percent when an average of 200 voicings or repetitions of a word were used to establish the code that represented the word. This system also demonstrated some ability to extrapolate between individuals.

Another system described by Arnold Lesti has been in operation for several years. The system, which is in the more general pattern recognition category, can be encoded in various manners. It can be established in a manner that emphasizes the characteristics of an individual voice and hence recognizes words only when spoken by the same individual. At the other extreme, by using voicings of many individuals, the code is generalized so that the word is recognized over a range of voicings such as men and women or indivuduals of different dialect.

The present state-of-the-art of speech recognition appears to be the ability to discriminate between sound vocabularies of perhaps several hundred words with some generalization among speakers. As generalization or tolerance for a range of individual speaker characteristics is increased, the accuracy of recognition of large vocabularies decreases. That is, there is a trade-off between generalization and discrimination. Phrases and short sentences can be recognized when words are distinctly spoken and care is taken not to slur adjacent words.

Response Devices

In an instructional system, as in an engineering process control system, communication between the human participant and the information-providing environment is a two-way channel. The human must be able to respond to states of the environment, dictate requests for appropriate action, and observe the actions or states of the environment. In order to input information of more than minimum content, the human is often required to use specialized devices whose operation must be learned and whose technique is generally different from that used in communicating with other humans. Hence, the human becomes burdened with operational details which do not contribute directly to the accomplishment of the instructional objectives. Increasingly sophisticated equipment and the development of problem-solving technique (e.g., pattern recognition) can remove some of the encoding burden placed upon the human and generally facilitate the communication between the human and the environment.

Requirements of response devices and techniques for the instructional process demand a wide range in both the nature of responses accepted and the degree of variability of particular responses. For example, in the early states of learning, wide response tolerances are acceptable and simple "yes-no" responses may suffice. As learning progresses, more precise responses to complex stimuli are desired which often require constructed responses with graphic and verbal properties. In keeping with the scope of this report, response devices included in this section consider only the interface aspects, that is, the nature of the equipment in direct contact with the human user. Also, discussion is limited to innovational devices capable of detecting overt responses and will not consider techniques of detecting such things as eye movement or brain waves.

General and Human Engineering Considerations

In order to increase effectiveness, response detection devices should be designed to place a minimum of constraint upon the user with respect to such control characteristics as position, expenditure of force, excessive interpretation or coding of response, or any actions competitive with common response habits. Also, response devices should be recognized as display devices since they guide the nature of the response and often are used to indicate the nature of the response performed. Hence, display requirements must generally be considered in the design of response detectors.

When several or many response devices are incorporated within an instructional environment, they should be arranged in a manner that provides not only clear visibility but also facilitates access without increasing the probability of inadvertent operation. In general, those devices which are active in most situations should be located near the center of the responding environment. It is generally desirable that active devices should also incorporate operational feedback such as an audible click or visual indication that confirms detection of the response.

For those devices having linear and near linear motions (such as levers) that are associated with linear displays, the control-display ratio (C/D ratio) becomes a significant parameter. This ratio is defined as the linear distance of control displacement to the distance of the resulting display movement; the control movement is measured at the position where the user's hand grasps the control. The optimum C/D ratio is that which minimizes the total time required to make the desired control movements within a specified error range. A number of different factors affect this ratio, including the display size, tolerance requirements, physical configuration of the device itself, and viewing distance. In general, empirical measurements are required to optimize the ratio for a particular design, and it has been shown that a good ratio can save from one to five seconds in positioning time (Jenkins & Connor, 1949; Jenkins and Karr, 1954).

To minimize error, the direction of movement of a control must be related appropriately to the change it induces in the associated display. In general, this relationship should satisfy existing design practice, standardization, and response norms. Response norms refer to control-movement habit patterns that are consistent from person to person without special training or instruction. For example, an inward or upward motion is almost always related to an "on" or activated state of a mechanism.

It will often be the case that several methods or techniquea are possible as response detectors for a particular environment. This is particularly true with an educational interface since it is frequently possible to structure subject matter in a manner that will be consistent with the devices selected. In an actual operating environment, factors such as cost, versatility, safety, reliability, and availability must be considered in relation to its value as a pedagogical device.

Experimental Devices

Techniques for communicating responses or instructions of a greater complexity than a simple "yes-no" or "start-stop" usually require a "letter writing" approach such as the typing of instructions on a typewriter keyboard or the manipulation of dials and switches in some specified manner. A more natural way of communicating non-trivial concepts would be to allow the user to indicate (i.e., point, illustrate) his desires by a manual or analogue procedure rather than through a verbal or textual-encoding procedure. At the present state of development these devices are experimental, expensive and require sophisticated logical equipment like a computer to operate the device.

Cathode-Ray Tube with Light Pen. One of the simplest ways of allowing a human to communicate with equipment is to provide the opportunity of allowing him to point to or sketch ideas which he wishes to communicate. Two approaches presently in the developmental stage provide this opportunity. One is the work previously mentioned of allowing response input through a combination of cathode-ray tube display and an associated light-pen response device. This technique which has largely been developed at the Massachusetts Institute of Technology under the project titled SKETCH PAD provides a computer controlled cathode-ray tube through which pictorial or textual data can be presented to a user. The associated light-pen is a photo-sensitive device which responds to the light generated at an intensified point on a cathode-ray tube face at which the pen is pointed. The electronic circuits associated with the pen then amplify, shape, and transmit the response back to the computer which interprets this response in a manner that allows the computer to determine the position at which the light-pen was pointing. The use of a few other associated controls such as buttons or switches now allow the computer to determine what action is to be taken as a result of the detected response. For example, a button labeled "draw" may indicate that the computer should now follow the motion of the pen and present a line across the cathode-ray tube face corresponding to the path through which the user directs the pen. The cathode-ray tube and light-pen possess extremely powerful properties not available to conventional paper and pencil in that the computer under program control can now manipulate the design as specified by the user. This intimate association of displays controlled by the logic of the subject matter and learner responses allows the student to investigate the subject matter in a way and at a rate not possible with other known approaches.

Typical characteristics of present-day devices are an active surface area of about 10 inches by 10 inches with light spot location specifiable to about one thousand points per vertical and horizontal dimensions or a total of one million discrete points. The amount of line or graph that can be displayed without noticeable flicker is between four hundred and eight hundred inches, depending upon the technique of generation. Techniques of tracking or following the motion of the pen easily provide for a drawing rate between ten and one hundred inches per second.

Graphic Pattern Detection. Another approach toward graphic pattern detection is work being carried out at both Massachusetts Institute of Technology and the Rand Corporation on the detection of stylus motion through electrostatic (or electromagnetic) pickup and coordinate encoding. Figure 3.20 depicts the general approach utilized with this technique. A grid of horizontal and vertical conductors are printed upon a suitable substrate with the ends of these conductors connected to input wires in such a manner that a series of pulses applied sequentially to the input wires will create a uniquely coded sequence at any point of the grid. The stylus when held near a point on the grid will then electrostatically pick up the coded sequence of pulses associated with that grid point. For example, Figure 3.20 shows a grid containing seven horizontal conductors and seven vertical conductors with the horizontal conductors with the horizontal conductors connected to input wires A, B, and C and the vertical conductors connected to input wires D, E, and F. For the stylus position shown in the figure, applying pulses sequentially to input wires A, B, C, D, E, and F will result in pulses picked up by the stylus at times corresponding to the time that inputs C, D, and E were pulsed. No pulses are detected at the times when A, B, and F are pulsed. As the stylus is moved from point to point a new code is obtained from the stylus depending upon its location on the grid.

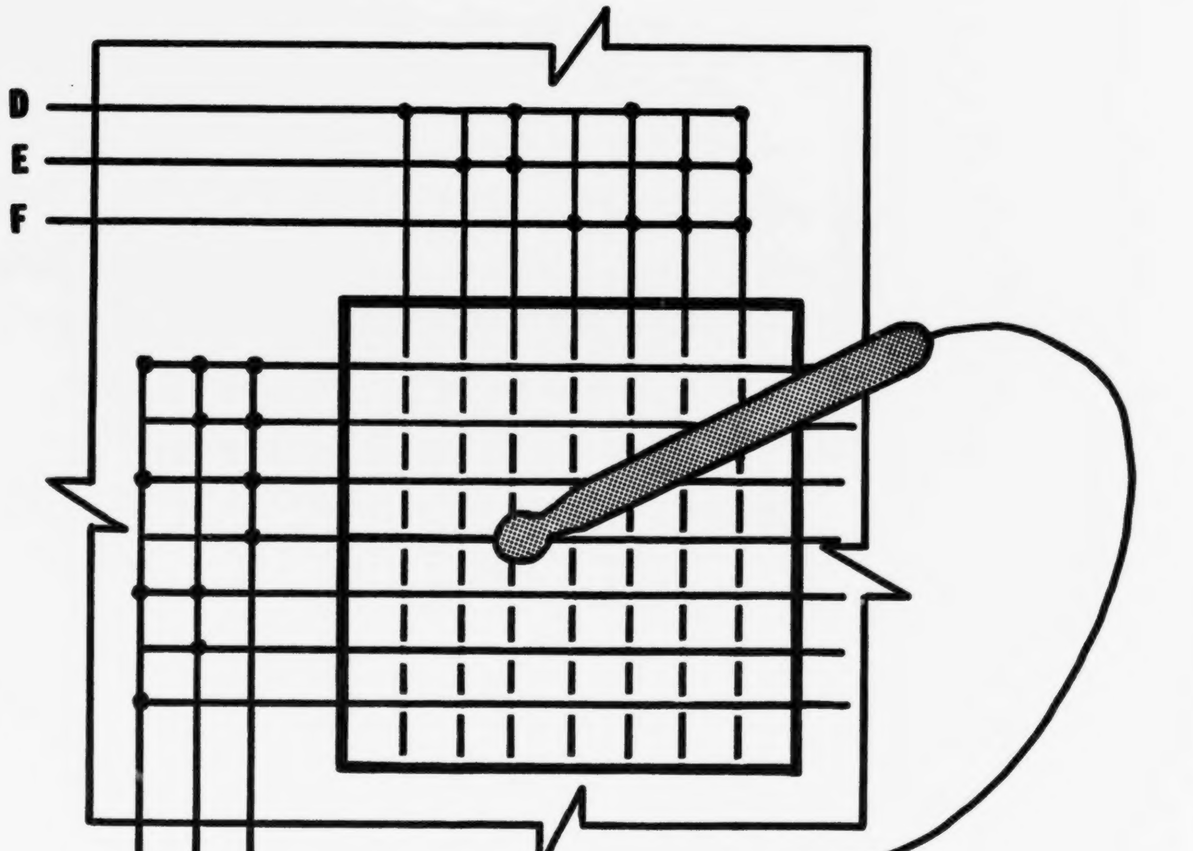

Fig. 3.20. Graphic Pattern Detector

As was the case with the cathode-ray tube and light pen, additional inputs may be provided with this detector to guide the program which is interpreting the input. For example, an additional switch perhaps located on the pen itself may indicate to a computer program that the pattern being detected should be displayed upon an oscilloscope or perhaps be processed in some manner different from that with an unactivated switch. This type of pattern detector obviously does not have the intimacy of display with response as that obtained with the CRT and light pen as shown in Figure 3.21. However, one interesting possibility with this type of input is that several stations may contribute to a common display on which each contributor can identify the location of his own pen. Several users, each operating at his own station but viewing a common display, may contribute to any part of the display and to the manipulation of the display itself. Present indications are that the input resolutions of devices of this sort are about 100 lines per inch and a tracking rate of 10,000 positions per second.

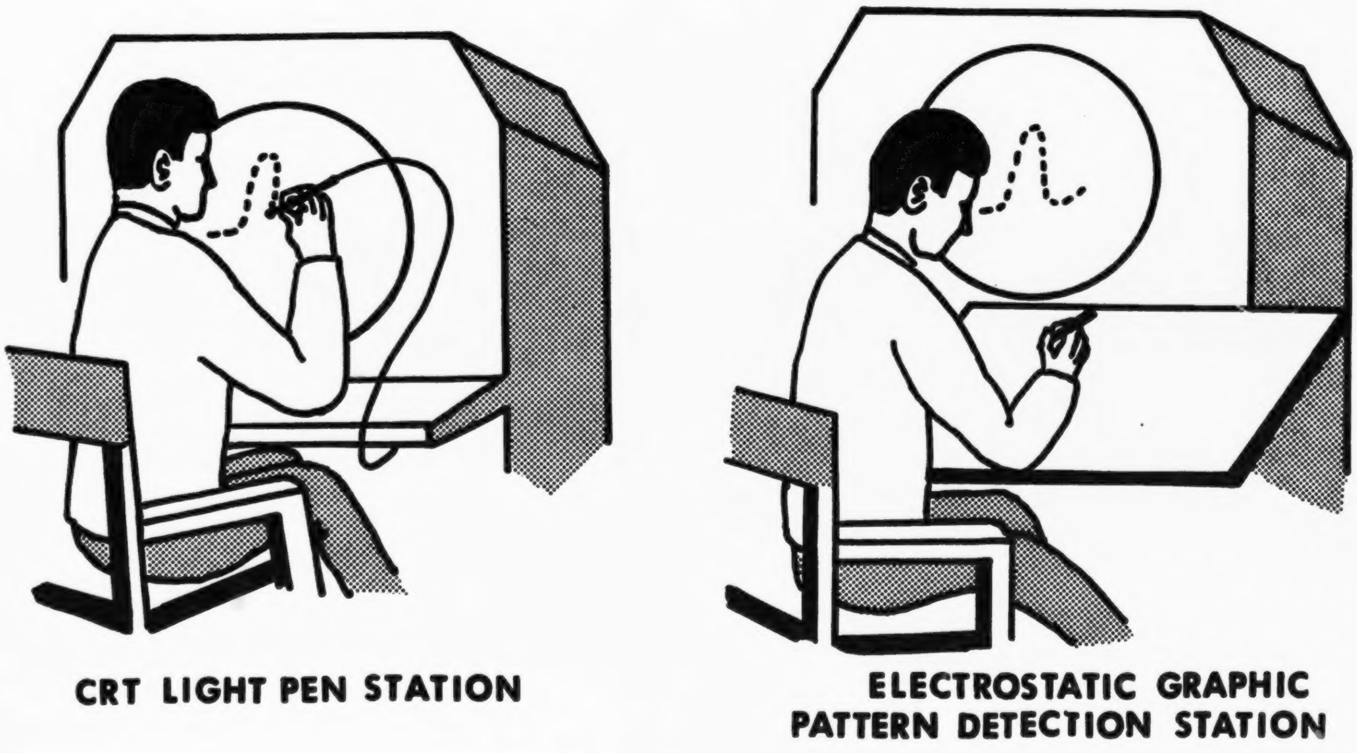
CRT LIGHT PEN STATION
ELECTROSTATIC GRAPHIC PATTERN DETECTION STATION

Fig. 3.21. Graphic Response Techniques

Touch-Sensitive Display. Another approach analogous to that of the cathode-ray tube and light pen but not requiring the manipulation of a pen with an attached wire is that of a touch-sensitive display. Figure 3.22 depicts one possible technique of implementing this approach: transparent material such as lucite is used to support a matrix of very fine wires. These wires are supported under tension in grooves cut so that normally the horizontal and vertical wires do not touch. When slight pressure such as finger pressure is applied at some point of the matrix, the horizontal and vertical wires come into contact and the short circuit which is created can be electrically detected to indicate what portion of the matrix is being touched. By covering this matrix of wires with a flexible, translucent and light-diffusing sheet of material, pictorial information can be projected through the assembly which now acts as a back-lighted display which is capable of detecting finger pressure response that is uniquely associated with some portion of the display being presented. This method of approach does not have the resolution of the cathode-ray tube, but for certain pedagogical situations, the approach may have adequate resolution and the advantages of technical simplicity. Signals from an assembly or device of this sort can be used as inputs to a computer program or some simple logic for selecting the next display to be presented.

Manipulation Board. Another response detector suggested by subject-matter requirements for young children is the "manipulation board" which is a surface capable of providing information concerning the identity and orientation of specific items located on its surface. This device would have the capability of providing information regarding patterns or arrangements of specific items such as children's blocks which can then be interpreted by associated equipment in accordance with a particular program. Figure 3.23 illustrates one possible approach towards the implementation of such a device. The surface is formed of a conductive grid which has embedded between each of its coordinates (each square cell) a pad of conductive material. Separate lead wires are attached to the grid and to each pad and are brought out for external connection to some encoding or interpreting network. The device operates by placing on the surface specific items that are capable of establishing a capacitive coupling

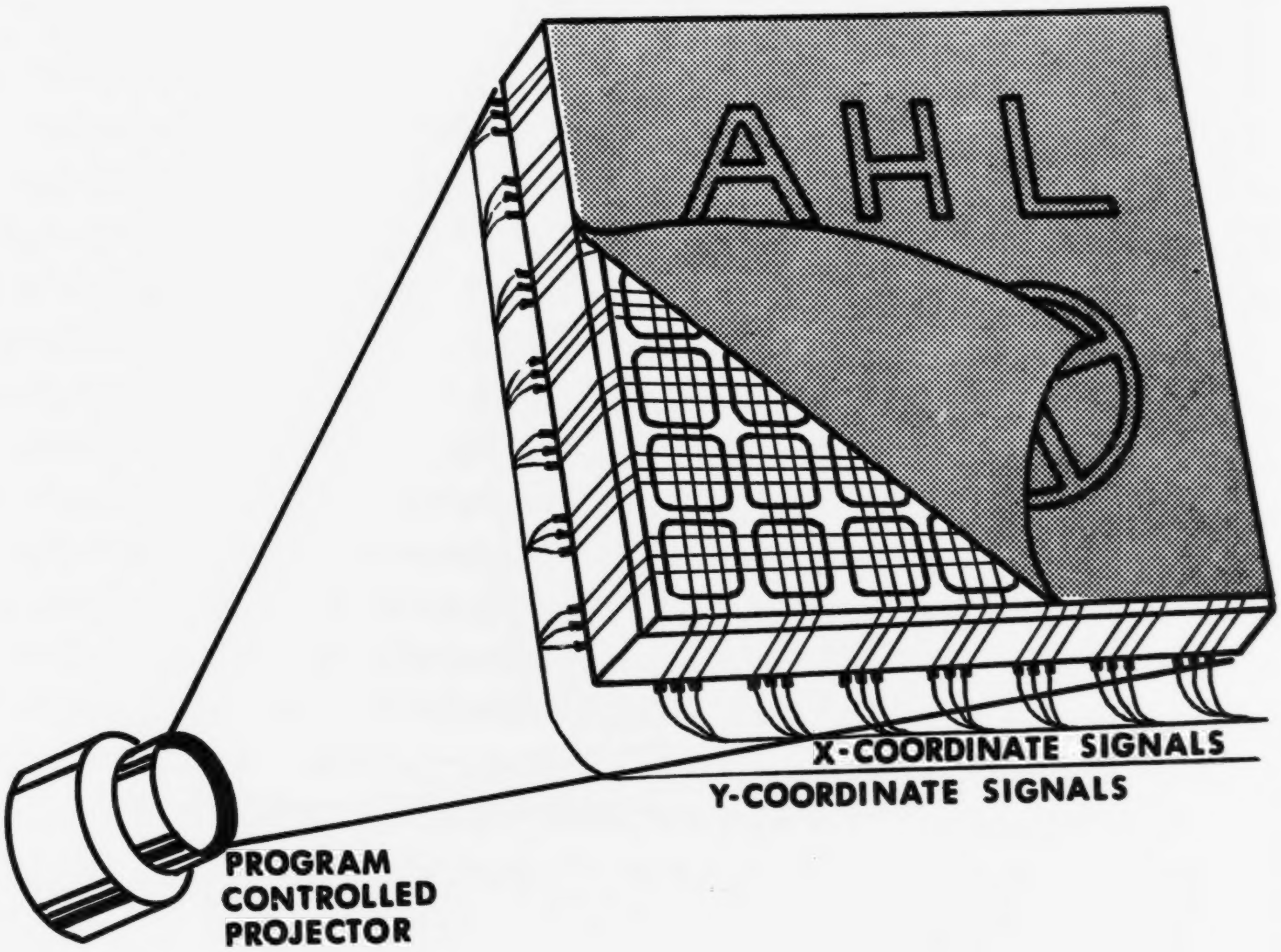

Fig. 3.22. Touch-Sensitive Display

between the grid network and the pads. A driving signal applied to the grid is coupled to those pads that are covered by the specially constructed items. Figure 3.24 shows a block of non-conducting material that has been plated with conducting material. Each block or each block type must have a unique area of plated material on its surface and sufficient unplated area at the edges to prevent two adjacent blocks from appearing as some larger block. The number of activated pads which are adjacent then provide an indication of the block type and its orientation. The analysis required by an interpretive program to determine the item identity, location, and pattern would be extensive. The rate, however, at which such patterns would have to be sampled is fairly low compared to present-day scanning and computation speeds. It is also quite possible that with fairly young children and with large blocks (1 cubic inch or larger) the resolution of

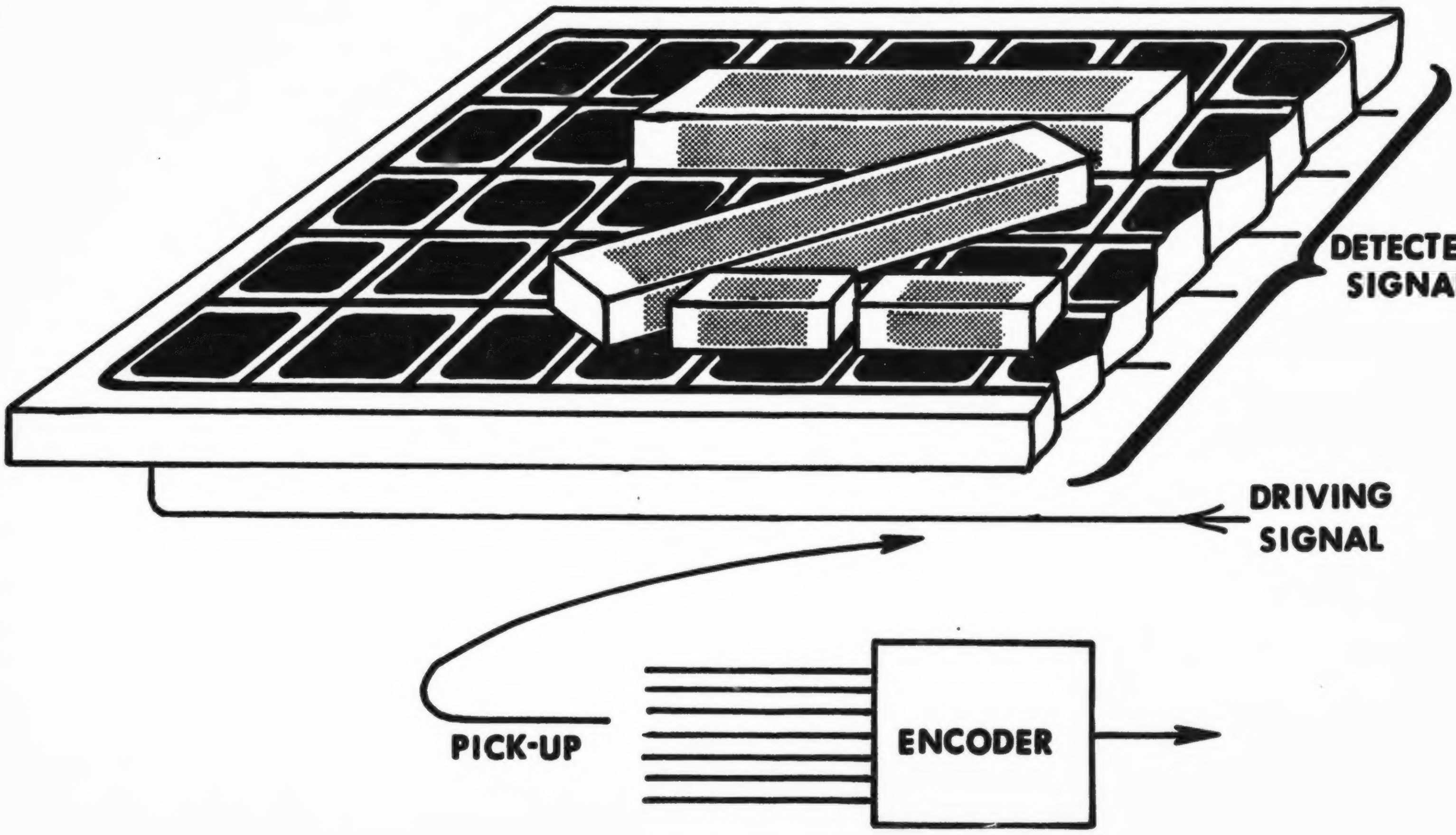
DETECTED SIGNAL
DRIVING SIGNAL
PICK-UP
ENCODER

Fig. 3.23. Manipulation Board

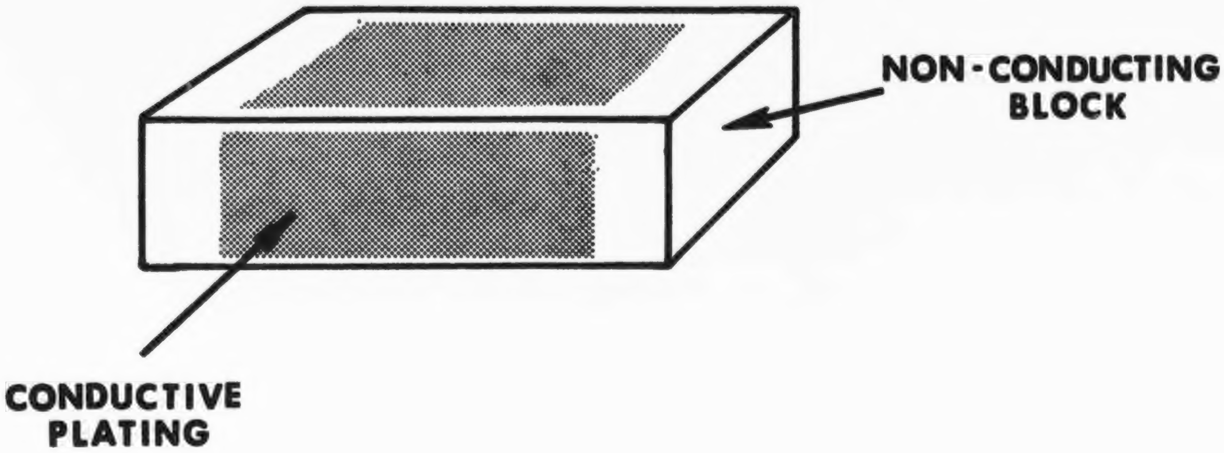
NON-CONDUCTING BLOCK
CONDUCTIVE PLATING

Fig. 3.24. Detectable Block

the surface need not be great, and the total number of detecting pads would not be an excessively large number. The geometrical configuration and the number of items that can be associated with a particular "manipulation board" is primarily a function of the board's resolution and the capability of the associated interpretive logic. Hence, the use of such a pad can be adapted to various subject matters depending upon what the items represent and programs associated with it.

Device Application

The preceding paragraphs have indicated the scope and trend of some of prototype and experimental techniques being explored which can be useful as response-detecting devices. The devices discussed obviously do not include all conceivable possibilities with existing technology. Closed-circuit television, for example, may provide a valuable response detector where again pattern-recognition schemes may be imployed.

The use of experimental devices is presently expensive both in the equipment required and the programming necessary to effectively use them. The additional versatility that such devices provide the subject matter programmer, however, requires their consideration in conjunction with subject-matter analyses as discussed in Chapter 2. The cost of these devices is also increased when they are used experimentally to study the learning process and include extra features which permit the manipulation of variables for study and the measurement of response characteristics of the learner. Those devices and methods that demonstrate improved instructional performance can then be developed on a production basis.

References

Cooper, F. S. Speech from stored data. IEEE International Convention Record, 1963, 137-149.

Estes, S., Kerby, H., Maxey, H., & Walker, R. Speech synthesis from stored data. IBM Journal of Research and Development, 1964, 8 (1).

Haley, E. J. Photochromic dynamic display. In J. H. Howard (Ed.) Electronic Information Display Systems. New York: Spartan Books, 1963.

Howard, J. H. (Ed.) Electronic information display systems. Washington: Spartan Books, 1963.

Jacobson, H. The informational capacity of the human eye. Science, 1951, 113, 292-293.

Jenkins, W. L., & Connor, M. B. Some design factors in making settings on a linear scale. Journal of Applied Psychology, 1949, 33.

Jenkins, W. L., & Karr, A. C. The use of the joy stick in making settings on a simulated scope face. Journal of Applied Psychology, 1954, 38.

Kelly, J., & Gerstman, L. Digital computer synthesizes human speech. Bell Laboratories Record, 1962, 40 (6).

Lesti, A. Universal recognition machine based on artificial intelligence. Company publication of the Andromeda Corporation, Kensington, Maryland.

Liberman, A., Ingemann, F., Lisker, L., Delattre, P., & Cooper, F. Minimal rules for synthesizing speech. Journal of Acoustical Society of America, 1959, 31 (11).

Morgan, C. I., Cook, J. S., III, Chapanis, A., & Lund, M. W. Human engineering guide to equipment design. New York: McGraw-Hill, 1963.

Olson, H. F. Speech processing systems. IEEE Spectrum, 1964, 1, 90-103.

Peterson, G., & Sivertsen, E. Objectives and techniques of speech synthesis. Language and Speech, 1960, 613.

Pollack, I. The information of elementary auditory displays. Journal of the Acoustical Society of America, 1963, 25.

Quastler, H. Info theory in psychology. Glencoe, Ill.: Free Press, 1956.

Sack, E. A., Wolfe, P. N., Asars, J. S. Construction and performance of an ELF display system. Proceedings of the IRE, 1962, 50, 432-441.

Sakai, T., & Doshita, S. The automatic speech recognition system for conversational sound. IEEE Transactions of Electronic Computers, 1963, EC-12, 335-345.

Shalaer, S. The relation between visual acuity and illumination. Journal of General Physiology, 1937, 21.

Stambler, I. Information display. Space Aeronautics, 1963, 40, 90-94.

Stotz, R. Man-machine console facilities for computer-aided design. Proceedings Spring Joint Computer Conference, 1963.

Sutherland, I. E. Sketchpad: a man-machine graphical communication system. Proceedings Spring Joint Computer Conference, 1963.

Sylvania Electric Products, Inc. Electroluminescent display devices. Bulletin 2009-IOMO (2) 12-60HP.

Underwood, B. J. Experimental Psychology. New York: Appleton-Century-Crofts, 1949.

Van Gelder, H. On-line stock quotation. Datamation, 1964, 10 (3).

Yando, S. A solid-state display device. Proceedings of the IRE, December, 1962.

Zworykin, V. K. & Morton, G. A. Television. New York: Wiley, 1954.

CHAPTER IV

RESEARCH AND DEVELOPMENT

Preface

The significant initial step to follow up the concepts discussed in the previous chapters of this report is to conduct research and development through a program of experimentation and feasibility studies. With respect to this step, Chapter IV presents the goals and tasks of such research, the special problems that can be investigated, the type of interface equipment indicated by subject-matter considerations and instructional requirements, and overall considerations with respect to computer and instructional programming.

Principal Tasks

In order to be productive in implementing the concepts which underlie a student-subject-matter interface, research and development would need to consider subject-matter instructional problems, equipment design problems, and investigations of the learning process.

Subject-Matter Analysis. Subject-matter analysis involves the study of subject-matter display, response, and feedback requirements in order to determine appropriate properties of the learning environment. Of particular interest here would be the extent to which close simulation of subject-matter features and extensive provision for the manipulation of subject-matter structure would elicit desired learning effects.

Instructional Analysis. The concern here is primarily with teaching techniques and student learning characteristics. In contrast to display and response features and their manipulation, which is the concern of subject-matter analysis, the emphasis is on instructional procedure. The variables that must be studied in this category include such things as the display mode preferred by the learner, the order or combination of display and response modes that maximizes transfer, and the kind of error correction or response prompting that facilitates learning.

The Development of Prototype Lessons. Related to the above functions is the task of constructing model lessons using the capabilities of the interface. These lessons should provide exemplary segments of subject-matter instruction and should be extensive enough to show long-range learning effects over a period of time more equivalent to school learning than a short-term experimental laboratory task.

Analysis of Learning Behavior. As a student proceeds through a lesson, the lesson can be designed so that basic learning experiments can be performed and so that a computer-based laboratory can pick off various measures of learning effects. These measures can include the degree of activity related to a subject-matter stimulus in terms of the rate of student response, response accuracy, and response latency (latency of response in learning experiments has proven to be a very sensitive measure of learning which is difficult to measure without instrumentation which can detect the short interval of time between stimulus presentation and student response). Other measures of learning, such a frequency and type of errors and number of trials to a learning criterion, can be detected and readily processed for analysis. Experimentation can proceed by comparing two differently constructed lessons which vary along some dimension such as delay of feedback. It may be possible, however, on the basis of careful monitoring of student performance, to vary certain properties of the experimental material, depending upon the response characteristics of the learner. This can provide more dynamic control of learning effectiveness and provide more information about learning over a short period of time than is possible in a more static experimental situation. For example, it should be possible to vary, depending upon learner response, such properties of a learning sequence as the rate of presentation of stimuli, the length of a learning block, the amount and kind of stimulus change produced by a response, and the order of concepts. In any event, a computer-based laboratory can provide very detailed experimental data concerning human learning.

Equipment Analysis. Related to the above functions of the laboratory is the analysis of equipment characteristics for design purposes. This analysis requires careful assessment of the equipment specifications necessary for certain subject-matter learning. The answers to such questions as how much fidelity is required in an auditory display, how much resolution is required in a picture, and how much maneuverability is required for control-display relationships, contribute to the development of equipment specifications which determine not only learning efficiency but economical production of the equipment itself.

Problems for Investigation

Basic Instructional Problems

The display, response, and monitoring capability of a research facility must permit a wide range of significant instructional problems to be investigated. Illustrative problem areas are described below:

Subject-Matter Instruction at Early Ages. Present day norms for when reading instruction or instruction in numbers should begin are based on various conceptions of maturation and child growth and development. Recent studies (Tyler, 1964) suggest a re-examination of these concepts. Maturational norms have been postulated on the basis of what takes place in most existing teaching environments, but do not say what is possible under new circumstances. Many of the readiness requirements which apply to teaching young children refer to the difficulties the child has in making motor responses such as pencil marks or making fine visual discriminations. Appropriate manipulanda and displays may often serve to overcome these difficulties. If it seems desirable to teach certain subject matters, such as reading, at an earlier age than is conventionally done, an appropriately designed interface could make such learning feasible. A problem for study, then, is the feasibility of employing for instruction specially designed interface materials which utilize the kinds of responses and discriminations with which young children must begin.

Studies in this problem area will consist of designing instructional lessons appropriate to the world and abilities of the preschool child. The development of such lessons will require (1) detailed assessment of the kind of display and response characteristics that maintain the kind of display and response characteristics that maintain the interest and self-sustained activity of the child and (2) the scheduling of interrelated, individual activity with an instructional interface, peer activities, and student-teacher activities.

The Parameters of Individual Differences. A long-standing datum of psychology is the fact of individual differences. The varied individual backgrounds that students bring to school have also been recognized by educators for a long time. However, in educational practice the fact is more often talked about than acted upon. Increasingly, however, the significance of individualization of instruction is being recognized (Henry, 1962; Goodlad & Anderson, 1963; Suppes, 1964). While the development of computer-based instructional systems can permit increasing individualization of instruction, an especially significant area for study is the relationship between measures of individual differences and conditions for learning. The success of aptitude test prediction depends upon the correlation between measured behavior before learning and final level of performance after learning. However, little systematic information is forthcoming from prelearning measures about how instruction should proceed in order to optimize instructional effectiveness. Detailed knowledge is required about the relationship between the present characteristics of the learner and the appropriate instructional environment required to permit him to attain educational goals. A direct approach to this area can be made with computer technology by using the computer to maintain long-term records of the progress of individual student learning and fitting the learning curves obtained to theory-based mathematical models. Since stable, longitudinal data will be obtained for each student, it seems possible to develop models of learning for various kinds of instructional tasks in which certain parameters of the model represent systematic individual differences.

Testing and the Assessment of Instructional Behaviors. In the light of current thinking about the educational process, the assessment of pre-instructional performance and the conduct of instruction must become more integrated procedures than they have been in the past. With this in mind, a significant problem is the investigation of the units of such interface devices as described in this report for testing and assessment functions, such as: individual testing, e.g., using the Stanford-Binet to obtain an IQ measure; the identification of learning preferences; and the assessment of problem-solving approaches to subject matter. Test constructors have indicated the desirability of sequential testing procedures whereby an individual is tested and then shifted to new levels if appropriate. It seems possible for a device to present test items in a variety of modalities, to sense the characteristics of the testees response, and to make decisions about the next item to be presented.

A related area for investigation is assessment of the methods by which a learner prefers to proceed through an instructional task. Such assessment can introduce a significant aspect into the individualization of instruction. Most present-day practices which attempt to individualize instruction (such as ungraded classes and programmed instruction) individualize primarily along one dimension, that of learner rate. Individualization in a broader sense should involve other dimensions of the educational process, such as differences in kinds of material that a learner likes to work from, self-initiated or highly directed activity, and his preferred study methods. As a research task, these preferences can be correlated with test measures; for instructional purposes, they can be used to prescribe certain kinds of lessons, at least in the early stages of learning

Optimal Steps in a Learning Sequence. In the course of an instructional sequence, the particular characteristics of a subject-matter stimulus presented to the learner determine his response to that particular learning step. The stimulus material may be too difficult in the sense that it contains too many items of information or it assumes mastery that has been only partially attained; on the other hand, it may be too simple in the sense that it requires a trivial and repetitious response or provides little reinforcing stimulus change. What is required of any individual learner is some means of anticipating the optimal learning step for him, based upon knowledge of his learning characteristics to that point. Studies along these lines would be of two kinds: (1) the determination of runs of subject response measure, latency, number of errors, amount of correction required, etc., that permit some prediction of the characteristics of the next learning step, and (2) some method of permitting adjustment by the learner of the characteristics of the next step in a sequence.

Overt Error Correction. The influence of student activity involved in the correction of erroneous responses has been an inadequately investigated aspect of student learning. It seems probable that the effects of overt correction function in a way similar to the reinforcement of correct responses; indeed, some experimenters have assumed that this is the case (Bower, 1962). The immediate and overtly displayed correction of errors can be implemented through appropriately designed interfaces, and the effects of error correction and investigation of optimal conditions for its use can be studied.

The Discovery of Reinforcers. The operation of reinforcement refers to the fact of behavior that certain products or contingencies of an activity serve to influence the further course of that activity. However, the specific products or events following an activity that serve as reinforcing stimuli need to be discovered for different situations and for different individuals. For some learners, knowing that they are correct may be reinforcing; for the other learners, the primary reinforcing event may be the presentation of a more challenging problem or permission to leave the situation. An adaptable learning environment can provide a wide range of contingencies in the course of subject-matter learning so that the particular contingencies which are reinforcing to a particular learner can be determined. Studies along these lines can be made to investigate individual differences in effective reinforcers and also to investigate improvements in learning efficienty as a function of the adjustment to these individual reinforcement characteristics.

The Reinforcement of Curiosity and Exploratory Behavior. As indicated in Chapter I, an extremely significant area for study is the development and maintenance of curiosity and exploratory behavior, using stimulus change as a reinforcer and incentive motivation. The responsiveness of the kind of environment suggested in this report for stimulus change can be quite useful for studies in this area. There are many questions that need to be studied, both with respect to the definitions of curiosity and exploration in various subject-matter tasks and with respect to the kind of learning situations which teach these behaviors.

The Teaching of "Aptitudes." Conceivably, a pre-school curriculum for children would not be the extension of formal subject matters down to younger ages. What might be considered is the teaching of behaviors which are more generally classed as aptitudes, assumed to be formed while the child is very young, for example, the ability to make fine pitch and rhythmic discriminations which are part of a musical aptitude. A research program along these lines would attempt to analyze in detail the prerequisite skills and concepts (similar to the learning-set analysis of Gagné, 1962) necessary for learning more complex behavior, such as beginning phonic concepts or beginning number-object relationships.

Experiments With Play, Freely Structured and Manipulative Activities. A long-standing research methodology in the study of child development is the observation of play and freely structured activities (Wright, 1960). This is somewhat related to the point above of assessing learning preferences. It seems possible to combine the area of observational child study with some of the rigor of laboratory experimental study (Bijou & Baer, 1960) by use of a computer-controlled environment. A wide range of stimulus and response possibilities can be provided, such as particular gamelike stations. A specific example for a child about to begin the study of elementary arithmetic concepts is observation through sensing devices which detect the characteristics of his manipulations of objects, that is, the orderliness and complexity of his arrangements.

This latter point, the study of object manipulation, seems especially significant since object identification and manipulation and similar tactile experiences underlie a large portion of kindergarten readiness activities. Beyond "readiness" activities, there has been for some time the teaching of arithmetic concepts through the manipulation of blocks (Gattegno, 1963). More recently, Bruner has discussed problem solving by children in terms of the use and study of manipulative activity (Bruner, 1964a; Bruner, 1964b). If experimental situations could be devised, studies in this important area of the manipulative responses of children would be accelerated.

Reduction of Abstraction Requirements and Performance Clutter. It seems possible with the aid of innovative interface devices to present subject matter to the student and have him manipulate it in a way which reduces the "inherent" difficulty of the subject matter. One aspect of difficulty may be that the subject matter task involves degrees of abstraction and concept formation by the student. Instruction in a subject matter might be made less difficult if certain of the abstractions involved in it were made more concrete. For example, in the teaching of functional relationships in mathematics, instruction in a conventional classroom might require that the student conceptualize how the slope and rate of change of a curve vary with different constants in an equation; however, with a cathode-ray tube display the student could directly manipulate parameters in an equation and observe the consequent changes in the function the equation represents (Licklider, 1962). Perhaps the attempt to make abstractions more overt can facilitate study of the ways in which students handle abstractions.

Competitive and Cooperative Instructional Systems. The use of cooperative and competitive instructional lessons in which students work with one another has interesting possibilities for study with a computer-based interface. Arithmetic problems and word problems can be displayed to a group of students who work at individual stations in order to manipulate a group display. Each student can be given a particular problem-solving function, or they can challenge each other by setting problems into their stations for the others to solve. The recorded responses can be used both as a means for guiding instruction for the participants and for analyzing group learning by the researcher.

Equipment Development Problems

In considering those components of the laboratory that may form a part of the interface between the student and the subject matter, conventional devices such as keyboards or slide projectors and movies are assumed to be available when required by a particular experiment. These devices may require modification in order to be adapted to the particular system being developed; however, such modifications would be principally technical adjustments for the linking together of different items of equipment whereas the functional operation of such devices would be similar to that normally defined for unaltered devices. For example, typewriters or typewriterlike devices are often used as computer input devices and although the operation of such typewriters is uniquely controlled by the computer, the actual manipulation of the keys and the responding of the typewriter to such manipulation is similar to that of a non-computer-controlled typewriter.

The interface devices discussed below are special devices that appear to be uniquely suitable to the instructional process as has been described in this report. Such devices do not exist other than in a prototype or developmental state, and part of the research and development envisioned would be the further specification and verification of the suitability of such devices and their engineering specifications. The guide lines under the items listed are those hypothesized to be suitable from a consideration of the subject-matter requirements and from what appears to be technically feasible.

Object Manipulation Devices. In certain subject areas like arithmetic or spelling it is felt that the ability to dispense and collect items bearing relevant symbols such as letters or numerals would be valuable. Devices similar to coin-changing machines which would operate under the control of a computer would thus be a component of the interface equipment. The items dispensed and collected would be coinlike plastic discs having embossed characters or symbols. A set of 32 possible types of discs that could be uniquely identified in a collector or dispensed under program control is desirable. Some variations in disc diameter could be accomodated, although it would appear more desirable that discrimination of the discs either be made on a weight basis or through notched edges or some other such means and that the variation of disc size be limited to two or three classes.

Another device used for the manipulation of objects is that described as a manipulation board in Chapter III. This board which would have the capability of detecting identity and orientation of a specific set of objects would be used in those subject matters where the character and relative relationship of different items is of significance. The set of different objects that can be discriminated by the board should be of the order of 10 or 12 for any one lesson.

Graphic Devices. One of the more manipulable displays is that which shall be referred to as "constructed displays" and was described in Chapter III under the general heading of "Cathode-Ray Tube Displays" with associated light-pen response detectors. Such displays, when associated with a suitable computer, provide the subject-matter programmer with the opportunity of accomodating display configurations that will not be constructed until the program is in actual operation with the student. That is, the programmer need not consider and make provision for large sets of displays in anticipation of a particular response by a student, but rather the program can be written to analyze a student's response and then compute or construct the display required. This ability provides a degree of manipulation of subject-matter symbols to an extent not possible with any other device presently known. Guide lines of such a device for the instructional environment would include a working area of approximately 10 inches by 10 inches. Black and white patterns are adequate although two or three levels of gray tone would give additional meaning to the displays. Since this display requires extensive service by associated computers if much information is being presented, it will probably be necessary to add buffering devices which store non-dynamic information which is being presented on the display.

Another device, referred to as the graphic pattern detector in Chapter III, can be used in much the same manner as that described above as "constructed-response device." In this system, the student's response is on one device whereas the results of that response are indicated on a separate display visible to the user of the input device. This device can be useful where two or more students may be responding to a common problem and sharing one common display media. Such an arrangement could conceivably be done with the "constructer-response device" described above, although the arrangement using graphic pattern detectors probably has economic advantages in operation. Another advantage of the graphic pattern detector is that its operation is such that the position of the associated pen can be detected no matter where the pen is placed on the detector; with the cathode-ray tube and light pen, a user generally must initially locate the pen by starting at a location already illuminated or one which has some symbol or character being displayed at the moment. Instructional guide lines for a device of this type would be a 12 inch by 12 inch overall size of active area, an ability to resolve character sets or symbols one-quarter inch or larger in height, and an operational speed that would allow it to follow normal handwriting speeds.

The touch-sensitive display is a device containing many of the features of the devices described above in that the student associates his responses directly with the display being presented. The device, however, would not have the resolution the above devices contain and probably would not have associated with it as large a set of possible displays. The advantage of this type of device, on the other hand, is its relatively light loading or demands on associated computing equipment while still containing a large set of possible responses. When used with projection equipment, the displays could contain all the advantages, such as color and good resolution, of film projection devices. Instructional guide lines for such a device would indicate an active area approximately 12 inches by 12 inches with individually touch-sensitive areas one and one half inches square (64 total areas). The requirement for the associated visual display device would be access within one second or less to approximately 100 different displays.

Auditory Devices. For auditory displays, the principal requirement is that of short access time to a reasonably large library of messages. For research purposes, it is felt that devices providing access of less than one second to about 100 messages, each message being of the order of eight to ten seconds in duration, would be suitable.

The recognition of audio sounds is one of the more difficult techniques of all those that have been discussed. Its apparent usefulness, however, to the instructional environment would indicate that research with existing techniques should be encompassed in order to explore the possibilities and merit of even a small set of recognizable sounds. For instructional purposes, therefore, the guide lines proposed are that the equipment be able to distinguish between 25 to 50 unique sounds of about one second in duration and that the recognition ability encompass a range of voices. For example, the set might include such sounds as letters of the alphabet, numerals, and perhaps standard phrases such as yes and no or plus and minus. The voice range to be accepted can be limited to male or female voices within an age span of three to four years. Since neither the student's response nor the recognition ability is accurate 100% of the time, an alternate stimulus for an unrecognized response might be "please repeat your answer." A device which could correctly recognize proper answers 95% of the time would seem satisfactory; this capability seems to have been achieved in certain instances for small character sets (Lesti, A; Olson, H. F., 1964). An additional, and probably necessary, requirement is that the character set utilized at any one time could be changed from lesson to lesson.

Support Tasks

A research and development project that encompasses the scope of student-subject matter interaction discussed in this report will require a major effort to implement and conduct. The project must have the continuity and range of subject material that will provide meaningful evaluations of both subject-matter structure and the interface components being developed. In order to implement a project of this type there will be subsidiary areas of work that must be accomplished so that the main stream of research can progress with adequate support. Although it has been generally assumed throughout this report that the logical capacity of a digital computer and associated special equipment such as audio devices were avialable where needed, it is recognized that the implementation and use of this type equipment will involve research and development of its own. It is the intent of this section to indicate just a few areas not discussed elsewhere in this report that will require serious consideration if the projected research and development is to be successful.

Computer Programming. The effective use of interface devices will generally require an associated data processing or logic capability equivalent to that obtainable through the use of digital computers. The operation of devices such as the manipulation board described in Chapter III can involve elaborate computer programs of detection and pattern recognition which are essential to their operation as well as to the manipulation of the subject matter involved. Where several devices are operating on a real-time basis, time-sharing and multiplexing procedures must be encompassed within the operating system that are compatible with the instructional requirements of the subject matter as well as with the efficient use of the equipment involved. Techniques of time sharing and multiplexing are being developed in other fields but their applications to the instructional environment must be investigated, and any requirements unique to this environment encompassed within the procedures.

In order to evaluate the devices and procedures under investigation, field tests and laboratory studies involving many hours of student learning need to be prepared and applied under spcified instructional conditions. The generation of such material is generally a time-consuming task involving much labor and field testing. In addition to the specification and development of the subject matter itself, the implementing of such material on a computer or related device so that it can be presented to the interface quickly is a major undertaking and requires much training, practice, and refinement before usable programs are generally available. To date, there are few aids such as programming languages to assist in the writing of subject-matter programs for computer presentation. The specification and development of such aids, however, is probably a requirement before significant amounts of subject-matter programs can be implemented on computer-like devices.

In addition to the programs and procedures for the operation of interface devices and for the presentation of subject matter through such devices, there are auxiliary or administrative programs necessary for the data-gathering and analysis task associated with the investigation of variables influencing learning and the evaluation of techniques under investigation. The programs may be common to several areas, but they will probably require continuous revision and the value of different measurements are better understood.

Auxiliary Facilities Required. Many, if not all, of the facilities and devices that have been discussed in this chapter will require auxiliary equipment for its operation. For example, the film projectors would probably need to be supplemented with cameras, film development and splicing and monitoring means in order to facilitate the research effort. Sound equipment would require recording and measuring facilities; in general, all equipment would require sufficient maintenance and operating personnel.

Measurement and Criteria. Progress in any field is enhanced as meaningful criteria and measures of performance are established. The establishment of such criteria as standards generally comes from a period of usage and general acceptance by an involved population. Hence, such standards and measures are not normally available in the formative years of a new technology. In the areas that have been discussed, most technologies are new and few widely accepted standards exist. The development, therefore, in all areas will have to proceed without the benefit of bench marks or guides, and a major contribution of work in this area can be such definitions and rules that may someday be accepted as criteria and measures of performance.

Research Environment. With regard to the layout of a research environment, it would appear that at least two different types should be provided. One of these would be designed for individualized study. In this type, the student would be surrounded only by components of the interface equipment, and the environment would be such that he would be free from distractions or other influences outside of those associated with the subject-matter presentation. Such an environment would require between 50 and 100 square feet of floor space and should be acoustically shielded from outside noise and interference. In some instructional situations, it may be desirable to have either an observer or tutor in the same area with the student undergoing individualized instruction. For these purposes, provision should be made to accomodate a second individual with room for note-taking or such activity as may be desired by a tutor.

Some means of indirect observation of the student may also be desirable; provision should be made for one-way viewing panels in one wall of the area or for closed-circuit television to monitor the activity of the student.

A second layout would be a larger area capable of accomodating from five to ten students to be used for research in the areas of cooperative instructional systems or general group instruction activities. This environment may contain equipment similar to that used in the individual stations although it may be operated and utilized in an entirely different manner. On the other hand, there will probably be need for equipment such as large displays that are visible to all members of the group or tables large enough for the entire group to work around. Since different subject matters may require grossly different configurations of equipment, one of the specifications of such an environment should be an ample number of electric outlets and equipment connection points to permit a maximum flexibility in equipment configurations. As was the case with the individualized environment, adequate acoustical shielding should be provided to present disturbance from outside noise, and provision should be made for adequate monitoring or viewing of the student's actions.

As has been indicated throughout this report, most of the interface equipment and subject matter considerations have assumed the existence of sophisticated, logical equipment such as digital computer to be available as required. Each such laboratory environment, therefore, would be provided with adequate ducting for access to a computer located elsewhere and to such other items of equipment as sound-reproducing or detection equipment and power supplies for specialized interface devices.

References

Bijou, S. W. & Baer, D. M. The laboratory-experimental study of child behavior. In P. H. Mussen (Ed.), *Handbook of research methods in child development*. New York: Wiley, 1960. Pp. 140-197.

Bower, G. H. An association model for response and training variables in paired-associate learning. *Psych. Rev.*, 1962, *69*, 34-53.

Bruner, J. S. The course of cognitive growth. *Amer. Psychol.*, 1964, *19*, 1-15. (a)

Bruner, J. S. Some theorems on instruction illustrated with reference to mathematics. In E. R. Hilgard (Ed.), *Theories of learning and instruction*. *Sixty-third yearbook of the National Society for the Study of Education*. Chicago: Univ. of Chicago Press, 1964. Pp. 306-335. (b)

Gagné, R. M. The acquisition of knowledge. *Psych. Rev.*, 1962, *69*, 355-365.

Gattegno, C. *Teachers commentary*. Mount Vernon, N. Y.: Cuisenaire Company of America, 1963.

Goodlad, J. I. & Anderson, R. H. *The nongraded elementary school*. New York: Harcourt, Brace, 1963.

Henry, N. B. (Ed.) *The sixty-third yearbook of the National Society for the Study of Education: individualizing instruction*. Chicago: Univ. of Chicago Press, 1962.

Lesti, A. *Universal recognition machine based on artificial intelligence*. Company publication of the Andromeda Corporation, Kensington, Maryland.

Licklider, J. C. R. Preliminary experiments in computer-aided technology. In J. E. Coulson (Ed.), *Programmed learning and computer-based* instruction. New York: Wiley, 1962. Pp. 217-239.

Olson, H. F. Speech processing systems. *IEEE Spectrum*, February, 1964, *1* (2).

Suppes, P. Modern learning theory and the elementary-school curriculum. *Am. Educ. Res. J.*, 1964, *1*, 79-93.

Tyler, F. T. Issues related to readiness to learn. In E. R. Hilgard (Ed.), Theories of learning and instruction. *The sixty-third yearbook of the National Society for the Study of Education*. Chicago: University of Chicago Press, 1964.

Wright, H. F. Observational child study. In P. H. Mussen (Ed.), *Handbook of research methods in child development*. New York: Wiley, 1960. Pp. 71-139.

APPENDIX

FORCE LESSON FOR SCIENCE INSTRUCTION

The following lesson is an example of what is termed a special purpose interface device which would be useful in teaching in a limited area of science and would have no widespread applicability.

Consider a lesson designed to show one aspect of the term force as used in physics: it is desired that the student learn that the displacement of a spring is a measure of the force exerted. Figure A.1 illustrates such a special purpose spring. In stimulus and response terms, when the student is shown a spring being stretched first one inch from its rest length, he should learn to respond that the force has been doubled. He should learn that there is a qualitative difference in the muscular effort required to double the extension. Another aspect of the terminal behavior being sought is the intuitive ability to utilize components of one or more forces to give a desired resultant force. Thus, if three springs are holding a ring in the center of a display table, when one of the springs has its tension altered, the ring will move from the center of the table. The student then is required to alter the tension in the other two springs by adjusting manual controls which are available to him. A display showing the tension in each spring and the component of force in a chosen direction can be used as a prelude to a more quantitative understanding of the addition of forces.

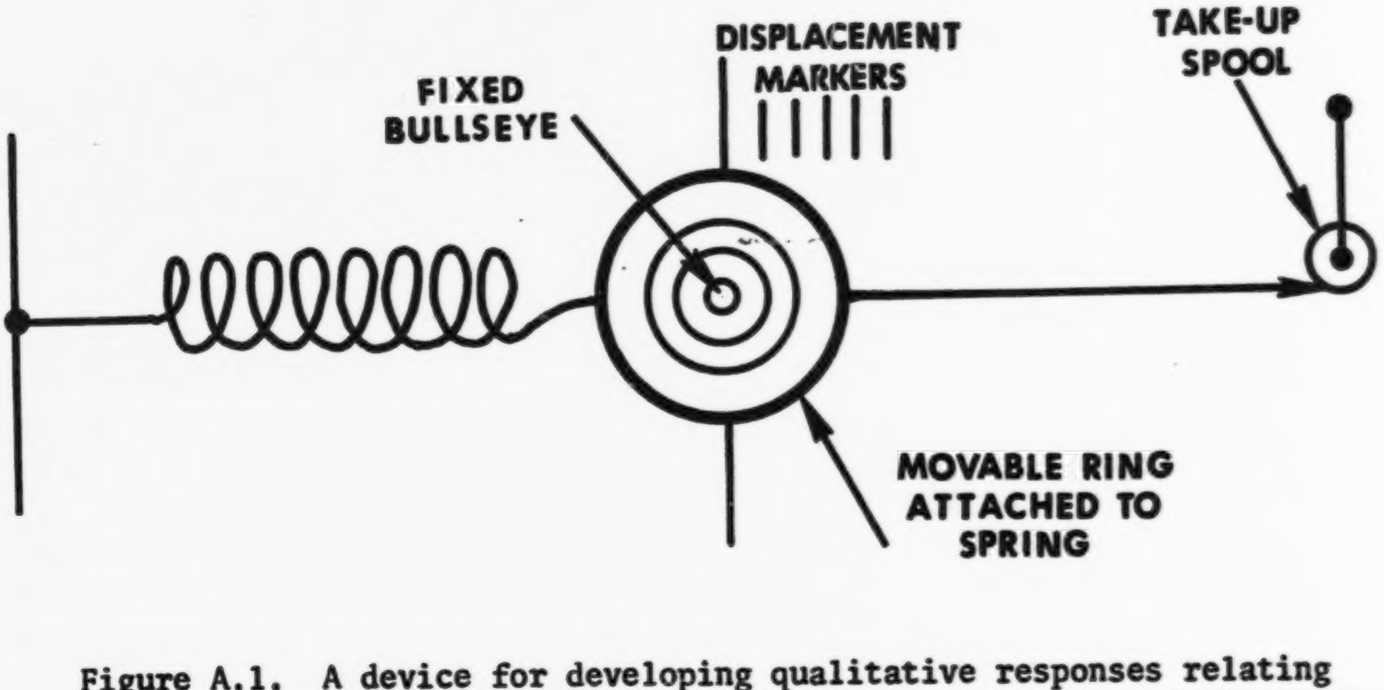

Figure A.1. A device for developing qualitative responses relating the force exerted on the take-up spool and the extension of the spring.

Determination of Entering Behavior

The student must be capable of adjusting both the springs and the spring controls upon direction. He should be able to read numbers and adjust a control until he obtains a number reading to match a number he has been given in an instruction.

Generalization Display

An element of generalization is introduced by using various types of springs in varying numbers. Another element of generalization may be introduced by using other natural springs such as pieces of rubber, thin wire, and nylon line. The tension display can be provided by a digital meter, an analog meter, an oscilloscope, a tone from an oscillator, a color hue, or light intensity. This enables the student to generalize that the force is independent of the display mechanism which informed the student of the magnitude of the force.

Gradual Progression

1. Establish the response required to extend a single spring (pull harder.)
2. Couple the word force to that which causes the spring to become extended.
3. Develop ability to measure extension numerically.
4. Develop ability to exert approximate force required for various extensions.
5. Associate intuitive muscular concept of more and less force to readings of a tension transducer (digital).
6. Use manipulatory knob to alter readings on tension readout and develop relation that doubling force doubles extension.
7. Develop response that force is required to move or extend the spring and that when the spring is held stationary in an extended position it must be pulling back on the ring as hard as the student is pulling on it.
8. (Figure A.2) Use two wires to develop concept that each wire supplying 1/2 force needed for a given extension is the same as one wire supplying the entire force.

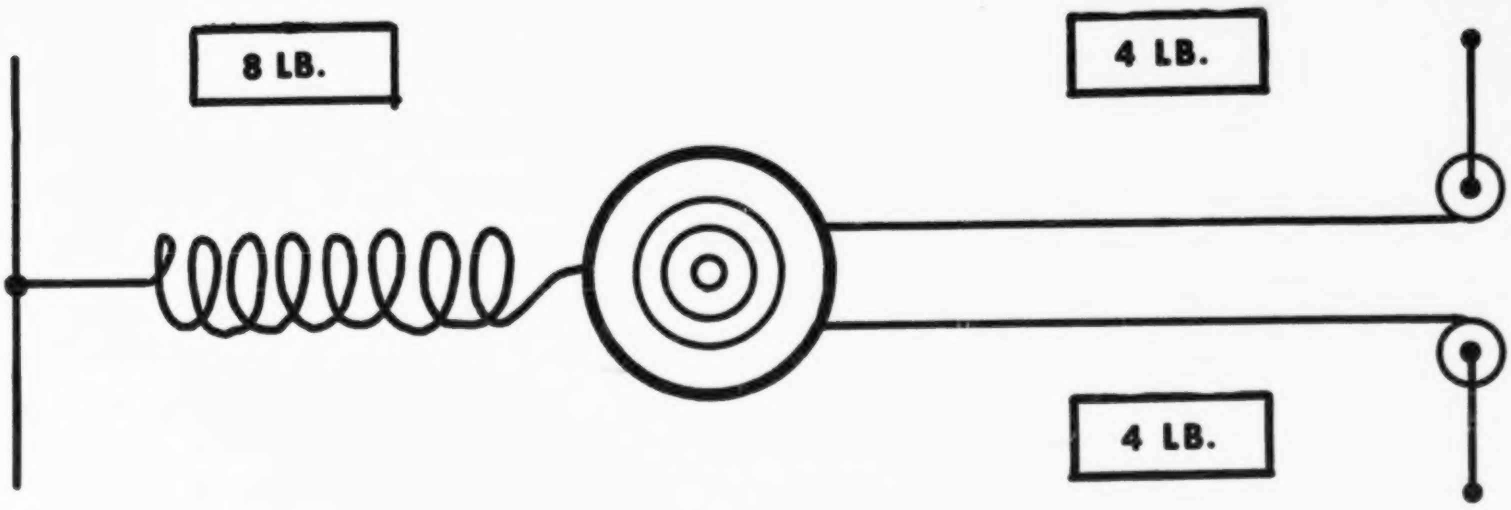

Figure A.2. A modification of device in Figure A.1 to show the quantitative as well as qualitative relation between the tension in the two wires and the force exerted on the spring.

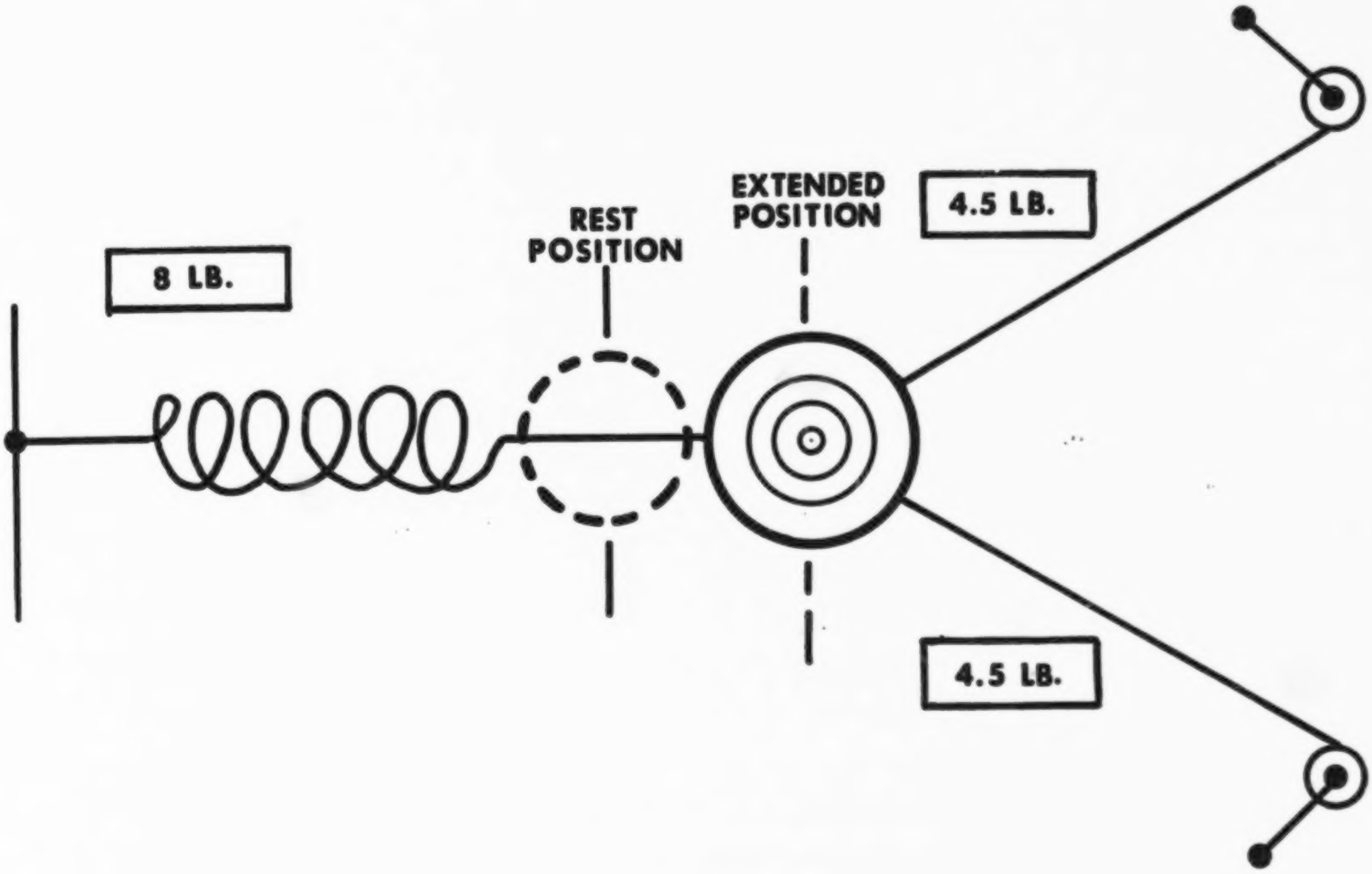
EXTENDED POSITION
REST POSITION
4.5 LB.
8 LB.
4.5 LB.

Figure A.3. A modification to show that the sum of the tensions in the wires may be greater than the force on the spring and that the effect is dependent upon the angle between the wires.

9. (Figure A.3) Put the wires at an angle to the line of the single wire and have the student make the discrimination (with the aid of the readout and muscular comparison) that the force on both wires exceeds that which the spring applies to the ring.
10. Have the student make discrimination that no attainable amount of force on the wire will allow them to be right angles to the spring if the spring is to be in an extended position (See Figure A.4).
11. Develop responses that the only part of the force that counts is the amount of force in the direction of the spring since the other components cancel each other (See Figure A.5).

For more advanced students, the following should be added:

12. Use readouts (Figure A.5) showing the components of force along the spring and at the right angles to the spring. Have student develop ability to adjust force readings to obtain extension by paying attention to components in direction of desired extension.
13. Place a different student on each wire and the spring with a take up spool. For a change in the displacement by one student, the task of the other is to adjust his wire to return the ring to the starting position as quickly as possible. Points are scored by least total during the game.
14. Extend above sequences to more wires and more springs.

Reinforcement

Usually activities with gross manipulative properties which result in a change in the display properties of the interface (numerical readout with clicking noises) are self-reinforcing. In addition, the following reinforcers are easily integrated into the lessons:

1. A light comes on in the bullseye when the ring has been returned to its starting position or to some chosen position.
2. Record is kept of the time to put ring into designated position. It is expected that shortened times to completion of task will prove reinforcing.
3. After completion of tasks a free play period with the force table is permitted.
4. Provide extrinsic reinforcers if none of the above work.

Prompting

Prompting may be provided by a trial button so that different combinations of force are applied with a commentary on the result. These can

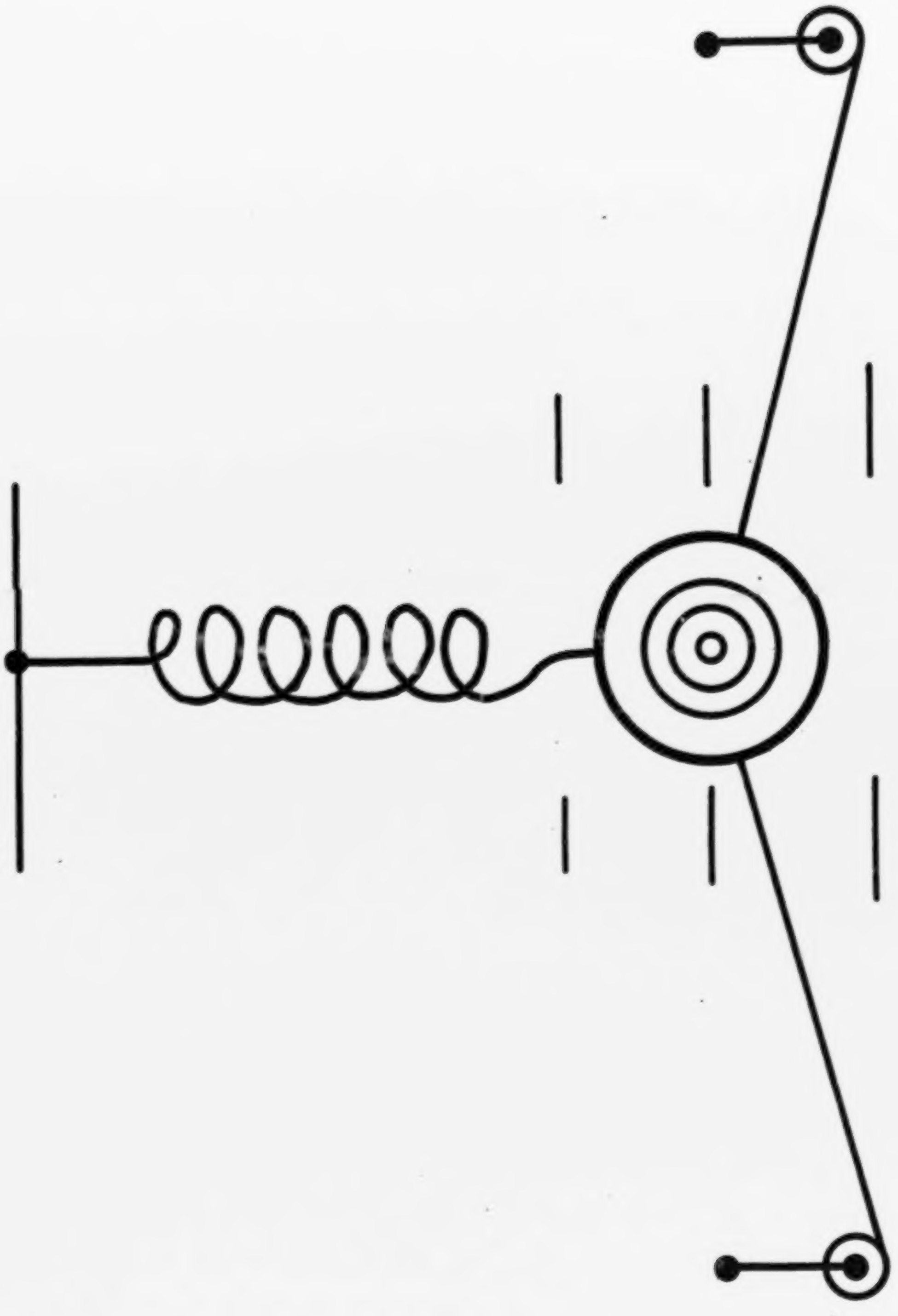

Figure A.4. Device in position approached for very large tensions in the wires. Student should observe that no matter what the tension, the wires cannot be brought perpendicular to the axis of the spring.

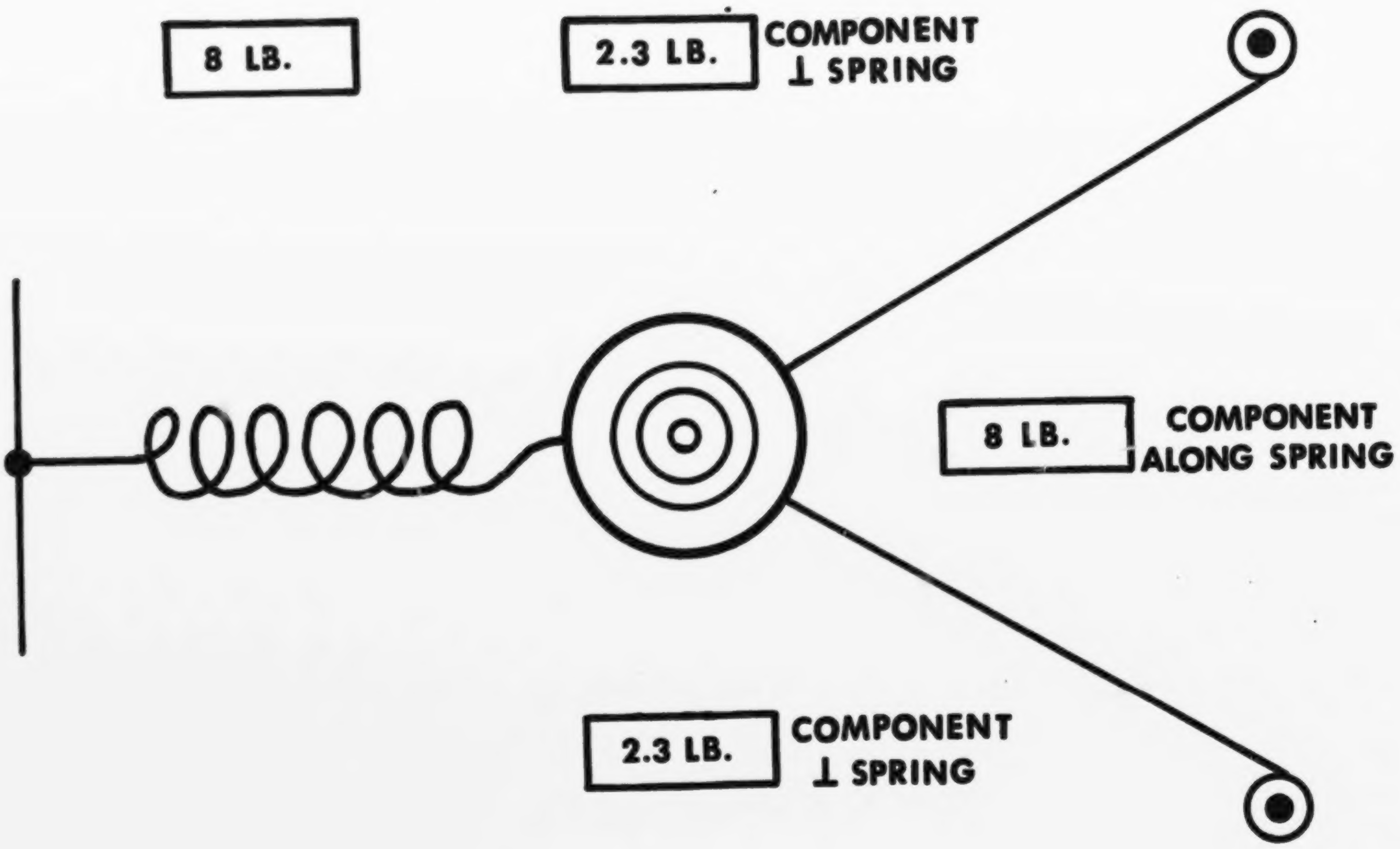
8 LB.
2.3 LB.
COMPONENT ⊥ SPRING
8 LB.
COMPONENT ALONG SPRING
2.3 LB.
COMPONENT ⊥ SPRING

Figure A.5. This figure shows additional readout components used to develop quantitative aspect of vector addition and subtraction of forces applied to the spring by the wires.

be structured in such a way that limited amounts of information are provided at the student's option. For the responses which do not require manipulation of the force applied to the ring, the manipulatory sequences should provide the basis for the verbal responses. Conventional prompts such as emphasizing certain words, offering a limited choice, colored guide lights, etc., may be used.

Fading of Prompts

As the repertoire of the student increases and he is able to use the concepts of force, equal force, greater force, direction of the force, he should be able to use the readout numbers and the position of the center ring to monitor the success of his performance. The use of prompts which are apart from the gradual progression procedure should be reduced in intensity. For example, the information supplied by the trial button should become less informative in indicating the response desired, until finally the trial or hint button will supply informative information which is not directly relevant to the task. Prompts such as guide lines, colored lights, can have their stimulus intensity reduced.